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ABSTRACT

While a number of different approaches have been suggested for the improvement of K-12 education in the United States, one common element of many plans is the more extensive and more effective utilization of computer, networking, and other technologies in support of a broad program of systemic and curricular reform. The Panel on Educational Technology was organized in April 1995 to provide independent advice to the President on matters related to the application of various technologies--in particular, interactive computer- and network-based technologies--to K-12 education in the United States. This report presents its findings and recommendations, which are based on a (on-exhaustive) review of the research literature and on written submissions and private White House briefings from a number of academic and industrial researchers, practicing educators, software developers, governmental agencies, and professional and industry organizations involved in various ways with the application of technology to education. The Panel's major recommendations include: focus on learning with technology, not about technology; emphasize content and pedagogy, not just hardware; give special attention to professional development; engage in realistic budgeting; ensure equitable, universal access; and initiate a major program of experimental research. The report contains an executive summary and ten sections: (1) Introduction; (2) Potential Significance; (3) Hardware and Infrastructure; (4) Software, Content and Pedagogy; (5) Teachers and Technology; (6) Economic Considerations; (7) Equitable Access; (8) Research and Evaluation; (9) Programs and Policy; and (10) Summary of Findings and Recommendations. (SWC)

EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES

PRESIDENT'S COMMITTEE OF ADVISORS ON SCIENCE AND TECHNOLOGY



# REPORT TO THE PRESIDENT ON THE USE OF TECHNOLOGY TO STRENGTHEN K-12 EDUCATION IN THE UNITED STATES

PRESIDENT'S COMMITTEE OF ADVISORS ON SCIENCE AND TECHNOLOGY

PANEL ON EDUCATIONAL TECHNOLOGY

MARCH 1997

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# Executive Summary

In an era of increasing international economic competition, the quality of America's elementary and secondary schools could determine whether our children hold highly compensated, high-skill jobs that add significant value within the integrated global economy of the twenty-first century or compete with workers in developing countries for the provision of commodity products and low-value-added services at wage rates comparable to those received by third world laborers. Moreover, it is widely believed that workers in the next century will require not just a larger set of facts or a larger repertoire of specific skills, but the capacity to readily acquire new knowledge, to solve new problems, and to employ creativity and critical thinking in the design of new approaches to existing problems.

While a number of different approaches have been suggested for the improvement of K-12 education in the United States, one common element of many such plans has been the more extensive and more effective utilization of computer, networking, and other technologies in support of a broad program of systemic and curricular reform. During a period in which technology has fundamentally transformed America's offices, factories, and retail establishments, however, its impact within our nation's classrooms has generally been quite modest.

The Panel on Educational Technology was organized in April 1995 under the auspices of the President's Committee of Advisors on Science and Technology (PCAST) to provide independent advice to the President on matters related to the application of various technologies (and in particular, interactive computer- and network-based technologies) to K-12 education in the United States. Its findings and recommendations are based on a (non-exhaustive) review of the research literature and on written submissions and private White House briefings from a number of academic and industrial researchers, practicing educators, software developers, governmental agencies, and professional and industry organizations involved in various ways with the application of technology to education.

A substantial number of relatively specific recommendations related to various aspects of the use of technology within America's elementary and secondary schools are offered at various points within the body of this report. The list that appears below summarizes those high-level strategic recommendations that the Panel believes to be most important:

1. **Focus on learning *with* technology, not *about* technology.** Although both are worthy of attention, it is important to distinguish between technology as a subject area and the *use* of technology to facilitate learning about *any* subject area. While computer-related skills will unquestionably be quite important in the twenty-first century, and while such skills are clearly best taught through the actual use of computers, it is important that technology be integrated throughout the K-12 curriculum, and not simply used to impart technology-related knowledge and skills. Although universal technological literacy is a laudable national goal, the Panel believes the Administration should work toward the use of computing and networking technologies to improve the quality of education in *all* subject areas.

2. **Emphasize content and pedagogy, and not just hardware.** While the widespread availability of modern computing and networking hardware will indeed be necessary if technology is to realize its promise, the development and utilization of useful educational software and information resources, and the adaptation of curricula to make effective use of technology, are likely to represent more formidable challenges. Particular attention should be given to the potential role of technology in achieving the goals of current educational reform efforts through the use of new pedagogic methods focusing on the development of higher-order reasoning and problem-solving skills. While obsolete and inaccessible computer systems, suboptimal student/computer ratios, and a lack of appropriate building infrastructure and network connectivity will all need to be addressed, it is important that we not allow these problems to divert attention from the ways in which technology should actually be *used* within an educational context.

3. **Give special attention to professional development.** The substantial investment in hardware, infrastructure, software and content that is recommended in this report will be largely wasted if K-12 teachers are not provided with the preparation and support they will need to effectively integrate information technologies into their teaching. Only about 15 percent

of the typical educational technology budget is currently devoted to professional development; this figure should be increased to at least 30 percent. Teachers should be provided with ongoing mentoring and consultative support, and with the time required to familiarize themselves with available software and content, to incorporate technology into their lesson plans, and to discuss technology use with other teachers. Finally, both presidential leadership and federal funding should be mobilized to help our nation's schools of education to incorporate technology within their curricula so they are capable of preparing the next generation of American teachers to make effective use of technology.

4. **Engage in realistic budgeting.** The Panel believes that at least five percent of all public K-12 educational spending in the United States (or approximately $13 billion annually in constant 1996 dollars) should be earmarked for technology-related expenditures—a significant increase over the current level of approximately 1.3 percent. Because the amortization of initial acquisition costs will account for only a minority of these recommended expenditures, schools will have to provide for increased technology spending within their ongoing operating budgets rather than relying solely on one-time bond issues and capital campaigns.

   While voluntarism and corporate equipment donations may be of both direct and indirect benefit under certain circumstances, White House policy should be based on a realistic assessment of the relatively limited direct economic contribution such efforts can be expected to make overall. The Administration should continue to make the case for educational technology as an unusually high-return investment (in both economic and social terms) in America's future, while seeking to enhance the return on that investment by promoting federally sponsored research aimed at improving the cost-effectiveness of technology use within our nation's elementary and secondary schools.

5. **Ensure equitable, universal access.** Access to knowledge-building and communication tools based on computing and networking technologies should be made available to *all* of our nation's students, regardless of socioeconomic status, race, ethnicity, gender, or geographical factors, and special attention should be given to the use of technology by students with special needs. Title I spending for technology-related investments on behalf of

economically disadvantaged students should be maintained at no less than its current level, with ongoing adjustments for inflation, expanding U.S. school enrollment, and projected increases in overall national spending for K-12 educational technology. Because much of the educational use of computers now takes place within the home, and because the rate of home computer ownership diverges widely for students of different racial and ethnic groups and socioeconomic status, consideration should also be given to certain public policy measures that might help to reduce disparities in student access to information technologies outside of school.

6. **Initiate a major program of experimental research.** The Panel believes that a large-scale program of rigorous, systematic research on education in general and educational technology in particular will ultimately prove necessary to ensure both the efficacy and cost-effectiveness of technology use within our nation's schools. Funding levels for educational research, however, have thus far been alarmingly low. By way of illustration, whereas some 23 percent of all U.S. expenditures for prescription and non-prescription medications were applied toward pharmaceutical research in 1995, less than 0.1 percent of our nation's expenditures for elementary and secondary education in the same year were invested to determine which educational techniques actually work, and to find ways to improve them.

   The Panel strongly recommends that this figure be increased to at least 0.5 percent (or about $1.5 billion annually at current expenditure levels) on an ongoing basis. Because no one state, municipality, or private firm could hope to capture more than a small fraction of the benefits associated with a significant advance in our understanding of how best to educate K-12 students, this funding will have to be provided largely at the federal level in order to avoid a systematic underinvestment (attributable to a classical form of economic externality) relative to the level that would be optimal for the nation as a whole.

   To ensure high standards of scientific excellence, intellectual integrity, and independence from political influence, this research program should be planned and overseen by a distinguished independent board of outside experts appointed by the President, and should encompass (a) basic research in various learning-related disciplines and on various educationally relevant technologies; (b) early-stage research aimed at developing new forms of educational software, content, and technology-enabled pedagogy;

and (c) rigorous, well-controlled, peer-reviewed, large-scale empirical studies designed to determine which educational approaches are in fact most effective in practice. The Panel does *not*, however, recommend that the deployment of technology within America's schools be deferred pending the completion of such research.

Finally, it should be noted that the Panel strongly supports the programs encompassed by the President's Educational Technology Initiative, which aim to provide our nation's schools with the modern computer hardware, local- and wide-area network connectivity, high quality educational content, and appropriate teacher preparation that will be necessary if information technologies are to be effectively utilized to enhance learning. In the area of research and evaluation, however, the Panel believes that much remains to be done. While a scientific research program of the sort envisioned by the Panel will require substantial funding on a sustained basis, such a program could well prove critical to the economic security of future generations of Americans, and should thus be assigned a high priority in spite of current budgetary pressures.

# 1. Introduction

While the importance of securing an adequate education for America's children has long been clear, this undertaking has, over the past fifteen years or so, acquired a sense of special urgency. On the one hand, expanded global competition and corporate restructuring have drawn attention to the importance of preparing the next generation of Americans to add value within an increasingly integrated world economy. Over this same period, however, serious concerns have been raised[1] regarding the capacity of the U.S. educational system to meet this challenge.

While a number of different approaches have been suggested for the improvement of K-12 education in the United States, one common element of many such plans has been the more extensive and more effective utilization of computer, networking, and other technologies in support of a broad program of systemic and curricular reform. Such proposals have been motivated in part by specific examples of the successful application of technology to education, and in part by the more general observation that, during a period in which technology has fundamentally transformed America's offices, factories, and retail establishments, its impact within our nation's classrooms has generally been quite modest.[2]

The *Goals 2000: Educate America Act*,[3] which was signed into law in 1994, contained a number of provisions designed to foster the application of technology within the nation's elementary and secondary schools. President Clinton has since announced several additional programs that aim to establish various forms of cooperative partnerships involving the federal government, the states,

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[1] Such concerns found expression, for example, in an influential report released in the early 1980s by the National Commission on Excellence in Education (*A Nation at Risk: The Imperative for Educational Reform.* Washington, D.C.: U.S. Department of Education, 1983).

[2] Indeed, Professor Christopher Dede has asserted that "if all computers and telecommunications were to disappear tomorrow, education would be the least affected of society's institutions." (Written statement submitted to the PCAST Panel on Educational Technology, 1995.)

[3] Public Law 103-227.

local communities, individual schools and school districts, and the private sector, in each case with the goal of mobilizing technology in service of K-12 education.

In the context of these various initiatives, the Panel on Educational Technology was organized in April 1995 under the auspices of the President's Committee of Advisors on Science and Technology (PCAST) to provide independent advice to the President on matters related to the application of various technologies (and in particular, interactive computer-based and digital-network–based technologies) to elementary and secondary education in the United States.[4] The Panel consists of seven PCAST members and five outside experts in the field of educational technology, and has been assisted in its activities by a small research and operational staff.

In the course of its investigations, the Panel reviewed a substantial body of existing written material on the subject of educational technology and solicited additional written input from a number of academic and industrial researchers, practicing educators, software developers, governmental agencies, and professional and industry organizations involved in various ways with the application of technology to education. A smaller group of individuals chosen from each of these categories were invited to meet personally with the Panel's members and staff in briefing sessions conducted at the White House in October 1995.[5] The Panel's principal findings and recommendations are incorporated in this report.

The report begins with a brief discussion of the nature of the problems now facing elementary and secondary education in the United States, and of the role technology might play in helping to solve those problems. Section 3 surveys the

[4] The Panel's focus on computer- and network-based technologies should not be taken to suggest that it believes other technologies ("distance learning" and other educational applications of television, for example, or even telephones and fax machines) to be either unimportant or unworthy of critical examination in an educational context. Such an examination is missing from the current report only because such technologies (along with such other important issues as the formulation of educational standards and the application of technology to post-secondary education and training) fall outside the scope of the Terms of Reference document that defined this panel's charge.

[5] A list of those individuals and organizations who provided written submissions to or participated in briefing sessions for the benefit of the Panel is included in the Appendix.

computing and telecommunications hardware (and equally important, the associated infrastructure and technical support) now deployed within our nation's schools, and considers the ways in which these resources will have to be expanded if educational technology is to be mobilized on behalf of all of our K-12 students. In Section 4, we consider the ways in which information technologies are actually *used* within our schools, and identify a number of challenges related to computer software, educational content, and pedagogical methods.

We continue in Section 5 with an examination of the role of elementary and secondary school teachers within a technology-rich educational environment, and of the professional development, ongoing support, and other resources that will prove necessary if teachers are to effectively integrate technology within their curricula. Current and projected costs associated with the introduction and continued use of technology within all of our nation's schools are estimated in Section 6, and are analyzed in terms of educational productivity and expected return on investment. Section 7 examines the issue of equitable access to educational technology, reviewing current and anticipated disparities based on socioeconomic status, race and ethnicity, geographical factors, gender, educational achievement, and special student needs, and considering some of the policy tools that might be used to minimize the extent and impact of these disparities.

Section 8 focuses on the need for rigorous scientific research designed to evaluate the effectiveness and cost-effectiveness of alternative approaches to the use of technology in education, on the extent to which such research should be funded at the federal level, and on the manner in which it might best be organized and administered. Current federal programs in the area of educational technology are reviewed in Section 9, with special attention to the directions in which those efforts might profitably be extended and expanded. The Panel's central findings and most important recommendations are summarized in Section 10.

# 2. Potential Significance

Since the effective utilization of technology within all of America's elementary and secondary schools will require a substantial investment of public funds, it seems appropriate to begin our discussion with a critical examination of the rationale for such expenditures. While much remains to be learned about the optimal use of technology in K-12 education, the Panel believes the case for educational technology to be a compelling one in view of certain critical economic and social problems now facing our nation and the weight of the available evidence regarding technology's potential contribution to the solution of these problems.

## *2.1 Serious Problems*

While the continuing expansion of international trade has the potential to confer substantial long-term benefits on American companies and workers, it also presents certain challenges. As trade barriers fall and cross-border transaction volume increases, our children will find themselves competing more directly with the citizens of other countries to provide goods and services within the world marketplace. Indeed, the effects of international competition have already become evident in the (permanent or temporary) loss of U.S. market share to European and Asian economic competitors within certain industries and in competition-induced productivity improvements which, while beneficial in the long term, have been accompanied in some cases by "corporate downsizing" and economic insecurity on the part of American workers.

Although it seems unlikely that the United States could reverse the secular trend toward global economic integration even if it believed this to be in its own interest, there is much we can do to influence the role that Americans play within the integrated world economy of the future. In particular, the decisions we make today with respect to the education of our children will determine in large part whether they are prepared to hold high-wage, high-skill jobs that add significant value within the world marketplace or are instead forced to compete with workers in developing countries (where economic output is likely to increase steadily over time) for the provision of commodity products and low-value-added services.

The danger of the latter scenario lies not only in its potential effect on our country's aggregate national income, but on the potential for unprecedented (at least within the American experience) disparities in income and wealth *among* Americans that could threaten the political stability our nation has long enjoyed. Our country's social fabric and democratic form of government have never been put to the test of supporting the extreme bimodality of resource allocation that might result (at least in the absence of aggressive redistributive intervention) if a relatively small percentage of our population were to possess the tools necessary to engage in highly-compensated economic activities, while a substantial majority were forced to compete with unskilled and semi-skilled laborers in developing countries who might well command (inflation-adjusted) wage rates of less than a dollar per hour.

These observations have implications not only for the *extent* to which we are able to educate our citizenry, but for the *way* in which we do so. In particular, it is widely believed that a continuing acceleration in the pace of technological innovation, among other factors, will result in more frequent changes in the knowledge and skills that workers will need if they are to play high-level roles within the global economy of the twenty-first century. Our children will thus need to be prepared not just with a larger set of facts or a larger repertoire of specific skills, but with the capacity to readily *acquire* new knowledge, to solve new problems, and to employ creativity and critical thinking in the design of new approaches to existing problems. In the words of Frank Withrow, the director of learning technologies at the Council of Chief State School Officers, "the U.S. work force does not need 'knowers,' it needs 'learners.'"[6]

## 2.2 The Role of Technology in Education

While the introduction of technology will not in itself improve the quality of American education, there are several ways in which the Panel believes it can be

[6] As quoted in Benton Foundation, *The Learning Connection*, <http://www.benton.org/Library/Schools-/connection.html>, 1996.

used as a powerful tool in addressing the problems outlined above. One of the earliest insights into the educational applications of technology was that interactive computer-based systems admit the possibility of individualizing the educational process to accommodate the needs, interests, proclivities, current knowledge, and learning styles of each particular student. Even the earliest drill-and-practice–based computer-assisted instruction systems, in which the student was exposed to successive blocks of textual material and answered a series of questions posed by the computer, typically offered the advantages of self-paced instruction. Among other things, self-pacing obviates the need for teachers to target their presentations to some hypothetical "typical" pupil, leaving part of the class behind while other students become bored, restless and inattentive.

In recent years, however, many researchers have begun to focus on the potential of technology to support certain fundamental changes in the pedagogic models underlying our traditional approach to the educational enterprise. Within this "constructivist"[7] paradigm:

- Greater attention is given to the acquisition of higher-order thinking and problem-solving skills, with less emphasis on the assimilation of a large body of isolated facts.
- Basic skills are learned not in isolation, but in the course of undertaking (often on a collaborative basis) higher-level "real-world" tasks whose execution requires the integration of a number of such skills.
- Information resources are made available to be accessed by the student at that point in time when they actually become useful in executing the particular task at hand.
- Fewer topics may be covered than is the case within the typical traditional curriculum, but these topics are often explored in greater depth.

[7] As used in this report, the term "constructivism" is intended to carry the meaning generally understood within the educational research community. Our intended usage should not be confused with references to "social constructivism" in the context of contemporary discussions of postmodernist theory—a very different notion that was neither considered nor discussed by the Panel.

- The student assumes a central role as the active architect of his or her own knowledge and skills, rather than passively absorbing information proffered by the teacher.

Some of the specific ways in which technology might be used within the context of the constructivist curriculum are outlined in Section 4.

Quite apart from its use by students, technology can serve as a potentially powerful tool for teachers, who may use computers and computer networks to:

- monitor, guide, and assess the progress of their students
- maintain portfolios of student work
- prepare (both computer-based and conventional) materials for use in the classroom
- communicate with students, parents, and administrators
- exchange ideas, experiences, and curricular materials with other teachers
- consult with experts in a variety of fields
- access remote databases and acquire educational software over the Internet
- further expand their own knowledge and professional capabilities

As noted in Section 4.4, a comprehensive approach to the learning process may also involve the use of technology by parents, and by other (physically proximate or geographically remote) community members. While the Panel has concerned itself only incidentally with the use of information technology in school administration, it should be noted that the effective utilization of technology can yield significant "back office" efficiencies for schools, freeing up resources for application to learning-specific activities.

## 2.3 The Promise of Educational Technology

Although our understanding of the effectiveness of various applications of educational technology remains incomplete, such research as is available, combined with anecdotal reports of the positive experiences of a number of schools, suggests that technology may indeed have the potential to play a major role in transforming elementary and secondary education in the United States. While a critical discussion of the existing research literature (and of the need for additional research) will be deferred until Section 8, a few of the better-known examples of the successful application of technology to K-12 education may help to convey an intuitive feeling for the potential of educational technology:[8]

- **Blackstock Junior High School (California):** This school has ten "smart classrooms," including one in which students can use computer-aided design (CAD) software to describe products that are then fabricated using a computer-controlled flexible manufacturing system. Higher test scores and improvements in comprehension, motivation, and attitude have been reported for the predominantly Hispanic student body.

- **Carrollton City School District (Georgia):** Computer technology is used in this school district as part of a novel program that has succeeded in reducing the dropout rate from 19 percent to 5 percent, and the failure rate in ninth grade algebra from 38 percent to 3 percent.

- **Carter Lawrence School (Tennessee):** Students in selected classrooms within this Nashville middle school used technology in various ways as part of a program called Schools for Thought, which is based largely on constructivist principles. Sixth-grade SFT participants scored higher on a number of components of Tennessee's mandated standardized achievement test than students in matched comparison classrooms, and demonstrated substantially stronger critical thinking skills in complex performance assessments involving high-level reading and writing tasks. Absenteeism and student withdrawal rates were also dramatically lower among SFT students.

- **Christopher Columbus Middle School (New Jersey):** Perhaps the most widely publicized example of the successful application of

[8] We have cited standardized test scores in a number of these examples solely because such scores are widely used as objectively quantifiable measures of educational achievement, and not because the Panel believes such metrics to be most appropriate for assessing those forms of knowledge and skills that should be regarded as most important for students to learn. The issue of appropriate metrics—especially for those forms of learning generally regarded as most important within the framework of the constructivist model—is discussed in Section 8.

educational technology, this inner-city school in Union City implemented a reform program that (along with other important changes) provided all seventh-grade students and teachers with access to computers and the Internet, both at school and at home. The performance of its 91 percent Hispanic student population, the majority economically disadvantaged, improved from significantly below to somewhat above the statewide average in reading, language arts, and math.

- **Clearview Elementary School (California):** A restructuring program involving the use of advanced technology resulted in an increase in standardized achievement test scores from the lowest 10 percent to the highest 20 percent.

- **East Bakersfield High School (California):** A school-to-work program at this school has made extensive use of technology to provide its 60 percent Hispanic student body (including many students having very limited English proficiency) with the skills required for any of five different career tracks, resulting in increased graduation and job placement rates.

- **Northbrook Middle School (Texas):** Interdisciplinary teams use computing and networking resources to teach critical thinking and problem-solving skills to this student population, which consists primarily of the children of migrant workers, 76 percent of whom are economically disadvantaged. Highly significant increases in test scores have been reported.

- **Ralph Bunche School (New York):** Information technology has been used for collaborative work and project-oriented learning by 120 randomly-selected students in this elementary school, which serves primarily low-income black and Hispanic residents of Central Harlem. These students outperformed a control group by ten percentage points in mathematics on New York City standardized exams. Progress has also been reported on problem-solving skills.

- **Taylorsville Elementary School (Indiana):** Self-paced individualized learning is the central focus of this suburban school, whose students are drawn largely from lower middle-class white families. Technology is used to support project work conducted by teams that include students of a mixture of different ages. Internet access and sophisticated information retrieval tools are used to support self-directed inquiries. While the program is relatively young, some improvement has been reported in test scores, along with a significant increase in student interest and enthusiasm for learning.

Rigorous, systematic, well-controlled research will ultimately be required to identify the specific factors responsible for such apparently successful outcomes and to ascertain their range of applicability and the extent to which they can be generalized. Most researchers and practitioners in the field of educational technology, however, are already convinced that information technologies have the potential not only to improve the efficacy of our current teaching methods, but perhaps more importantly, to support fundamental changes in those methods that could have important implications for the next generation of Americans.

# 3. Hardware and Infrastructure

Although elementary and secondary schools in the United States have for some time been acquiring new computing and networking hardware faster than they have been retiring old equipment, access to modern hardware remains a significant impediment (though by no means the *only* impediment) to the widespread application of technology within grades K-12. The amount of equipment available for instructional purposes remains suboptimal relative to the country's K-12 student population, and a large fraction of the equipment that is available to the schools is obsolete and of very limited utility. This problem is compounded by a lack of appropriate infrastructure for the operation of modern computer and networking equipment, and by a shortage within the schools of trained personnel capable of supporting the use of such equipment.

## *3.1 Computers and Peripherals*

One commonly employed measure of the penetration of computers into American schools is the ratio of students to computers. Over the years since microprocessor-based personal computers first became widely available, this ratio has declined significantly, dropping from 125 in the 1983-84 school year to 10.5 in 1994-95.[9] This figure, however, still falls short of the ratio of four to five students per computer (which has been achieved by only a very small minority of all U.S. public schools) that many experts consider to represent a reasonable level for the effective use of computers within the schools. Middle and junior high schools have less access to computers than senior high schools on a per-student basis, and elementary schools have an even higher student/computer ratio.

As a result of the relative scarcity of computer equipment, most schools locate the majority of their computers not within the individual classrooms, but in

[9] Quality Education Data, Inc. (QED), *Technology in Public Schools, 14th Edition* (Denver, CO: Quality Education Data, Inc., 1995), p. 15.

specialized computer labs that are shared among all classes.[10] If lab use is carefully scheduled, this approach can offer the potential for certain cost efficiencies through higher equipment utilization. On the other hand, the sequestration of a school's computers within a computer lab makes it more difficult to use these tools on an intermittent basis as an integral part of various elements of the curriculum.[11] About half of all teachers have at least one computer in their classrooms, but most have no more than two, making student computer use by individuals and small groups impractical within most classrooms.

The computer access problem is exacerbated by the fact that most of the computer systems now in use within the public schools would be considered obsolete by private sector standards.[12] While such machines are able to run certain early educational applications (including some drill-and-practice systems), little or no new software is being written for these platforms, and they would in any case be incapable of supporting much of the functionality incorporated in the most interesting current applications of technology to education. A 1992 survey by the International Association for the Evaluation of Educational Achievement (IEA)[13] revealed that only about 20 percent of all school computers were equipped with hard disk drives, thus further limiting the range of accessible software and databases. Nearly 90 percent of all printers owned by American schools were then based on dot-matrix technology, significantly limiting both the speed and quality of digital output, and laser printers were exceedingly rare, especially in elementary and middle schools.

One measure that has been proposed to ameliorate or eliminate the shortage of computer equipment within the schools is the donation by corporations of used computer equipment at the time it is replaced with newer models. While

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[10] Becker's analysis of computer coordinator data from the International Association for the Evaluation of Educational Achievement (IEA) Computers in Education Study, 1992, found that 70% of all middle and junior high schools located most of their computers within their computer lab. See Henry J. Becker, *Analysis and Trends of School Use of New Information Technologies*, report prepared for the Office of Technology Assessment, U.S. Congress (Washington, D.C.,1994), p. 18.

[11] As Kathleen Fulton observes, "It's a bit like having to share books, or schedule the use of pencils." See Kathleen Fulton, *Technology for K-12 Education: Asking the Right Questions,*" commissioned paper for the National Center for Education Statistics (Washington, D.C.: Issue Dynamics, Inc., 1996), p. 9.

[12] QED, *Technology in Public Schools*, 14th Edition, p. 26.

[13] IEA Computers in Education Study, 1992, as reported in Becker, *Analysis and Trends*, p. 19.

it is possible that such an effort could be beneficial under certain circumstances, the Panel believes that this is not likely to have a *major* effect on the computer hardware problems now facing American schools for several reasons. First, such equipment would generally be at least one generation behind the then-current state of the art as of the time of donation. Although this might well represent a modest improvement over the current situation in many schools, we believe the "obsolescence gap" between the computers used in American industry and those used in American education should be more aggressively attacked in order to end the technical isolation that has thus far drastically limited the range of software and functionality available to most schools.

Perhaps less obviously, however, the net effective life-cycle cost of donated equipment may actually prove to be *higher* than would be the case with purchased equipment. Unless a given school receives a large number of identical machines, such donations can raise costs substantially by increasing the number of different platforms that must be integrated, administered, and maintained by school- and district-level personnel. Even in the absence of such considerations, older equipment tends to be more expensive to maintain in usable condition than new machines—a potentially significant factor, since the average cost of administering and maintaining a computer system over the course of its useful life has been shown to be surprisingly high relative to the value of the hardware itself (as discussed in Section 3.5).

When these less visible costs are taken into consideration, the net value of a corporate equipment donation may in some cases actually be *negative*—particularly after accounting for the loss of public revenue attributable to federal and state tax deductions claimed by the donor.[14] Although the above considerations should not preclude the use of donated equipment under *all* circumstances,[15]

[14] Indeed, any equipment whose actual value (after taking into consideration projected maintenance and other personnel-related costs) has dropped below that of the legally allowable tax writeoff is likely to be systematically *preferred* by the corporation as a candidate for donation. Unless the school is able to operate such equipment more efficiently than the donor corporation (a tenuous assumption at best), such a donation may have the (after-tax) effect of a transfer of wealth *from* the public sector (defined to include both the school and all applicable taxing authorities) *to* the corporation—the exact opposite of the intended outcome.

[15] Regardless of the economic value of any given equipment gift, it is perhaps worth noting that corporate donation programs may well have significant collateral benefit to the extent they help to draw the private sector into closer contact with our schools.

the Panel believes that it would be unrealistic for the Administration to expect such donations to make more than a relatively small contribution overall toward ameliorating the current shortage of modern hardware.

It is also important that educators and policy-makers view the purchase of computer equipment not as a one-time expenditure, but as an ongoing cost. Although technological change in the computer industry is difficult to predict with any certainty, a useful life of between three and five years (which is longer than the typical life cycle in industry) may represent a realistic expectation for our schools, assuming that the criteria for replacement include not only age-related malfunction, but also obsolescence and the inability to support then-current software. In short, it seems inevitable that a significant investment of funds will be required on the local, state, and/or federal level to provide and maintain the sort of computer hardware that our schools are likely to need to support meaningful educational reform.

## 3.2 *Building Infrastructure*

The extensive use of computers, particularly where interconnected by a local area network, imposes requirements on school buildings that were in many cases not anticipated at the time of their construction. "Our building, built in 1948," notes one respondent to a General Accounting Office survey, "was wired for a filmstrip projector."[16] The satisfaction of many (though not all) of these requirements will require extensive and costly rewiring of several sorts.

First, as computer/student ratios continue to drop, the computers, peripheral devices, and other technology installed in each school may draw more current (at least in certain locations) than the AC wiring of many schools can support,[17] requiring the retrofitting of additional power capacity within existing buildings. In addition, most (though not all) current local area networks are based on the

[16] U.S. General Accounting Office (GAO), *School Facilities: America's Schools Not Designed or Equipped for 21st Century* (Washington, D.C., 1995), p. 13.

[17] In a survey of 10,000 schools conducted between January 1994 and March 1995 by the General Accounting Office, 35 percent of all respondents reported that their school had insufficient electrical power to support computer and communication technologies, while 46 percent reported inadequate electrical wiring for such technologies. (GAO, *School Facilities*, p. 12.)

use of physical cables for data transmission—something very few American schools were designed to accommodate.[18] Access to the Internet and other wide area networks will also require that schools be wired for one or more external connections, which may be provided, for example, over telephone or cable television lines.

The vast majority of all American classrooms, however, are not even wired for telephones,[19] much less local area networks and Internet onramps. To make matters worse, many schools have asbestos within their classroom walls, making an already challenging wiring and cable-routing task even more expensive. Although volunteer efforts like the NetDay '96 initiative (which was organized to wire a large number of California schools to the Internet) have illustrated the contribution that community members and cooperative unions can make toward outfitting our schools with the infrastructure necessary to support modern computer networking, it seems unlikely that such efforts can be relied upon as the sole mechanism for providing universal access to technology throughout our nation's schools.

Although wiring *once* may represent an unavoidable expense, conservative advance planning may at least obviate the need to wire *repeatedly* to accommodate future growth and unanticipated changes in technology. Although it may be slightly more expensive initially, it is important that resources be made available to allow our schools to install the sorts of flexible and capacious conduits, raceways, and wiring systems that will support the later installation of future generations of higher-speed interconnection technologies (based on fiber optic cable, for example) without the need for extensive surgery on schoolroom walls. In this regard, we would do well to follow the example of hockey player Wayne Gretzky, who has said, "I skate to where I think the puck *will* be."[20]

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[18] Sixty-one percent of all respondents to the GAO survey indicated that they lacked conduits or raceways for computer-to-computer network cables. (GAO, *School Facilities*, 1995, p.12.)

[19] Fewer than one classroom in eight contains a telephone that can be used to make outside calls. See Thomas K. Glennan, Jr. and Arthur Melmed, *Fostering the Use of Educational Technology: Elements of a National Strategy* (Santa Monica, CA: RAND Corporation, 1996), p. 20.

[20] The Panel is indebted to John Bryson and Michael Hopkins for calling its attention to this quotation and its applicability to the issue under discussion.

It should also be noted that the placement of significant numbers of computers within the same room can result in enough additional heat dissipation to require air conditioning in schoolrooms that do not currently have such facilities, or to require the provision of additional cooling capacity in those that do. Moreover, air conditioning consumes additional electrical power, adding hidden costs to the expense of installing and operating such environmental control systems.

In short, providing our schools with an educationally optimal configuration of computer and networking equipment will require significant expenditures not only for the purchase and maintenance of that equipment, but for the wiring and upgrading of older school buildings to accommodate new technology. The panel believes, however, that such expenditures represent an important investment in the future of the American public school system that is warranted by the associated economic and social returns that can reasonably be expected.

## 3.3 Local Area Networks

Local area networks (LANs) are important not only to connect computers, printers, and other devices together within a given school, facilitating important forms of communication among students, teachers, administrators, and support personnel, but also to provide many or all of these computers with access to systems at remote locations through the Internet or other wide area networks (WANs). A 1992 study reported that only about 20 percent of all school computers were connected to a LAN, though nearly a third of all elementary schools and one-half of all high schools reported that at least *some* of their computers were interconnected in this manner.[21]

It would appear that the use of locally-networked computers by K-12 schools may be growing at a relatively rapid pace: A (perhaps not entirely comparable) survey conducted shortly thereafter by a different organization found that 44 percent of elementary schools and 66 percent of high schools had local area networks.[22] The use of LANs for instructional (as opposed to administrative)

[21] IEA Computers in Education Study, 1992, as reported in Becker, *Analysis and Trends*, p. 68.

[22] Survey by Market Data Retrieval Corp., as reported in Becker, *Analysis and Trends*, 1994, p. 19.

purposes would also appear to be enjoying a period of unusually rapid increase. According to a third source, only 5 percent of all public schools used LANs for instruction during the 1991-92 school year; three years later, this figure had risen to 33 percent.[23]

While wiring problems remain an obstacle to the provision of more widespread local connectivity, as noted in Section 3.2, it is possible that wireless local networking technologies based on the use of low-power radio frequency communication may ultimately provide a viable alternative for at least some older schools in which physical wiring would be complicated by asbestos or other factors. The trajectory of future decreases in the cost of transceivers and interfaces for wireless networks may be among the determinants of the more widespread adoption of such technologies.

## 3.4 Wide Area Networks

About half of all public schools had at least one connection to the Internet as of fall 1995, and another 11 percent to a wide area network that was not connected to the Internet.[24] Although it is encouraging that 61 percent of our schools (up from 49 percent just a year before) are now connected to wide area networks (WANs) allowing at least some form of communication with remote sites, these connections are used only modestly by teachers, and are often unavailable for use by students.

While a substantial majority of all schools with Internet connections report that access is available to teachers, for example, a survey commissioned by the National Education Association and other education groups found that only 16 percent of all teachers actually make use of the Internet or online services.[25] Even among schools having access to a WAN, 72 percent reported that teachers

[23] QED, *Technology in Public Schools*, 14th Edition, p. 91.

[24] U.S. Department of Education, National Center for Education Statistics (NCES), *Advanced Telecommunications in U.S. Public Elementary and Secondary Schools* (Washington, D.C., 1996), p. 8.

[25] As reported in Benton Foundation, *The Learning Connection*, <http://www.benton.org/Library/Schools-/connection.html>, 1996.

either never used this network or used it only "to a small extent."[26] In cases where WANs are made available for student use, access is often provided only within a centralized library, media center, or computer lab rather than within individual classrooms, where it might be more extensively utilized as part of the process of day-to-day learning.[27]

Internet access is more commonly available in secondary schools than in elementary schools, and larger schools are more likely to be connected than smaller ones.[28] In the vast majority of all schools with Internet access, connections are made through ordinary modems; higher-speed connections are still very uncommon.[29] Until greater external network bandwidth becomes more widely available within the schools, many (current and future) Internet applications having an extensive audio and/or graphical component (and in particular, those involving the extensive use of three-dimensional renderings or moving images) will remain too slow for practical use.

Among the principal determinants of the extent to which American schools are able to make use of the Internet and other wide area networks is the availability of reasonably priced telecommunications services of adequate bandwidth to support the interactive use of network-based applications (including those with a substantial multimedia component). A sustained federal commitment to the maintenance of a genuinely competitive telecommunications environment—not only within the long distance market, but among alternative local carriers

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[26] NCES, *Advanced Telecommunications*, p. 14.

[27] Among those schools that had a connection to the Internet as of fall 1995, a majority provided access within at most one classroom (NCES, *Advanced Telecommunications*, p. 11). Overall, Internet access was provided within only nine percent of all instructional rooms—a rather dramatic increase over the three percent recorded in 1994, but still quite small in absolute terms (p. 12). It would seem, however, that these statistics may (or may not) have been affected by a potential ambiguity regarding the intended meaning of the survey question "How many rooms used for instructional purposes (include classrooms, labs and media centers, etc.) have connections to the Internet?" (Question 7b). In particular, it seems possible that a respondent whose school had a single *physical* Internet connection, but employed a local area network to provide Internet *services* within multiple rooms, may have been confused as to the appropriate response.

[28] Nearly two-thirds of all secondary schools had some form of Internet access as of fall 1995, but less than half of all elementary schools. Only 39% of all schools having an enrollment of less than 300 students reported having an Internet connection, as compared with 69 percent of those schools with more than 1,000 students. (NCES, *Advanced Telecommunications*, p. 9.)

[29] Only seven percent of all public schools that had access to a WAN were connected by means of a T1 link as of fall 1995, and only ten percent had a 56Kb connection. (NCES, *Advanced Telecommunications*, p. 15.)

as well—should play a major role in reducing the cost of access for our nation's schools. In addition, however, consideration should be given to measures designed specifically to promote affordable Internet access for American schools, with special attention to those in remote rural areas and to those facing resource limitations that would otherwise preclude the possibility of securing and maintaining such a connection.

## *3.5 Systems Administration and Technical Support*

It has been estimated that the purchase price of a computer system represents only 20 to 25 percent of the cost of its operation over the period of its useful life within a typical business; the largest part of the life cycle cost of such a system is actually represented by the cost of installation, training, systems administration, user support, and hardware and software maintenance. While the Panel was unable to find reliable data that might shed light on any systematic differences between the operating costs reported in industry and those experienced by the typical elementary or secondary school, it seems likely that the effective life cycle cost of operating a computer within a school environment is in fact an integer multiple of its original acquisition cost, particularly in view of the longer service period typical of computers used within the schools.

Portions of this effective expense may in many schools be incurred in the form of staff time diverted from other, often unrelated functions. An analysis of the 1992 IEA survey data found that only six percent of all elementary schools and three percent of all secondary schools have full-time computer coordinators. Indeed, only about 40 percent of all schools have even a single employee who allocates time in an official capacity to the operation of computer systems.[30] In schools having access to a wide area network, support is most commonly provided by a part-time network administrator associated with the school, although some WANs are administered at the district level.[31] The extent to which limited support for local- and wide-area networks has retarded the widespread utilization of technology within the public schools remains unclear, but experi-

[30] IEA Computers in Education Study, 1992, as reported in Becker, *Analysis and Trends*, p. 64.

[31] NCES, *Advanced Telecommunications*, p. 16.

ence within the business sector suggests that this may indeed represent a significant obstacle.

Of particular relevance to the schools is the fact that the cost of maintaining a given computer system tends to increase over time, especially when measured relative to the functional capacity or market value of the underlying hardware. While a portion of this increase is attributable to ordinary component- and system-level aging, this effect is exacerbated (again, in value-relative terms) by the use of progressively higher levels of integration within the semiconductor, digital storage, and computer industries. Older equipment uses more integrated circuit chips, more printed circuit boards, and more moving parts (disk drives, cooling fans, and print engines, for example) to realize the same amount of processing power, data storage, and output capability, and system reliability tends to be inversely correlated with component count and with the number of connections between components. This observation has significant implications for initiatives based on the donation to schools of equipment retired from service within corporations, as discussed in Section 3.1.

# 4. Software, Content and Pedagogy

"One of the enduring difficulties about technology and education," notes Dr. Martha Stone Wiske, co-director of the Educational Technology Center at the Harvard Graduate School of Education, "is that a lot of people think about the technology first and the education later, if at all."[32] If the federal government is to play a meaningful role in applying technology effectively within the nation's elementary and secondary schools, the deployment of computers and their interconnection within local- and wide-area networks must not be viewed as an end in itself. Indeed, such hardware, while important, is in many ways less central to a discussion of the determinants of favorable outcomes than the educational content, pedagogic models, and organizational framework that define the manner in which it is used.

## *4.1 Computer-Based Tutorial Systems*

Among the earliest applications of computer technology within the field of education were systems designed to automate certain forms of tutorial learning. Such systems, which were first deployed on an experimental basis during the 1960s, are commonly referred to using the (now confusingly general) term *computer-assisted instruction* (CAI). In a classical CAI application, short blocks of instructional material are presented to an individual student, interspersed with questions designed to test that student's comprehension of specific elements of the material. Questions must typically be posed within a multiple-choice or "true/false" framework, or in such a way as to admit a simple, concrete answer (such as a numerical quantity) that can be interpreted by the system in a straightforward manner.

Feedback is generally provided to the student as to the accuracy of his or her responses to individual questions, and often as to the degree of mastery demonstrated within a given content area. As noted in Section 2.2, CAI systems typi-

[32] As quoted in Peter Appleborne, "Computer Idea Gets Mixed Response: Questions about Cost and the Best Strategies for Education," *New York Times*, January 25, 1996.

cally allow students at least some degree of control over the pace of instruction. Such systems generally also support "branched" structures, in which the student's performance on one question, or degree of mastery of one content area, determines the sequence, and in some cases, the level of difficulty, of the instructional material and questions that follow. Additional time can then be spent on material with which the student is having difficulty, while avoiding needless repetition of subject matter that has already been mastered.

More "intelligent" CAI systems may be capable of inferring a more detailed picture of what the student does and does not yet understand, and of actively helping to diagnose and "debug" the student's misapprehensions and erroneous conceptual models. If a student is having difficulty learning to subtract, for example, the computer may recognize that he or she is systematically failing to "borrow a one," making it possible to offer specific coaching rather than a simple repetition of the original instructional material. While promising early examples of such systems have already been demonstrated in such content areas as mathematics and computer programming, realization of the full potential of this approach will require significant research progress in several areas. In the absence of such progress, it is not clear that highly intelligent tutorial systems will be available for wide deployment within the schools for some time.

Although some of the more recent work on computer-based tutorial systems may well prove useful within a constructivist framework, conventional CAI systems have historically been employed primarily for individual instruction in isolated basic skills, most often in a "drill-and-practice" mode. Instructional sessions have generally focused on a single content area rather than on the integration of a wide range of skills to solve complex problems, and have been limited in duration to the traditional 50-minute class period.

The conventional approach to CAI is often embodied in network-based systems known as *integrated learning systems* (ILSs), which have typically incorporated computing and networking hardware, systems software, tutorial content, and student record management programs, all provided by the same vendor. As of 1990, approximately 10,000 such systems had been installed in the United States,[33] and penetration is currently estimated at some 30 percent of all Ameri-

[33] Therese Mageau, "ILS: Its new role in schools," *Electronic Learning* 10 (1990), p. 22.

can schools. ILS facilities have seen particularly heavy use in remedial instruction, and in the context of programs for the educationally disadvantaged;[34] certain (positive and negative) aspects of such applications are discussed in Section 6.

## 4.2 The Constructivist Model

The tutorial applications discussed in the previous subsection are for the most part compatible with the pedagogic models traditionally employed within our nation's schools. In recent years, however, many have argued that the use of new technologies to improve the efficiency of traditional instructional methods will result in limited progress at best.[35] This view holds that the real promise of technology in education lies in its potential to facilitate fundamental, qualitative changes in the nature of teaching and learning.

While the educational research community has by no means reached consensus on the best way to educate our children, a large part of that community has in recent years converged on a core set of pedagogic principles that form the basis of the constructivist paradigm (introduced briefly in Section 2.2). By contrast with the more traditional view of instruction as a process involving the transmission of facts from an active teacher to a passive student, constructivists believe that learning occurs through a process in which the student plays an active role in *constructing* the set of conceptual structures that constitute his or her own knowledge base.

Although the intellectual roots of constructivism considerably predate the current educational reform movement, contemporary constructivist thought has been strongly influenced by models of the learning process that have evolved over the past few decades within the cognitive science research community, and which differ in significant ways from those which arose within the theoretical framework of behaviorism. Constructivist theory has given rise to an ap-

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[34] Glennan and Melmed, *Fostering the Use of Educational Technology*, p. 4.

[35] Charles Vest warns of problems analogous to those encountered initially within the U.S. manufacturing sector when American firms attempted to exploit new robotic technologies without rethinking the nature of the manufacturing enterprise. (Comments at Panel subgroup meeting, 1996.)

proach to educational practice that places the locus of initiative and control largely within the student, who typically undertakes substantial, "authentic" tasks, presented in a realistic context, that require the self-directed application of various sorts of knowledge and skills for their successful execution. Such activities often involve student-initiated inquiries driven at least in part by the student's own curiosity,[36] and are designed to motivate students in a more immediate way than is typical of traditional curricula based largely on the transmission of isolated facts.

Constructivist curricula often emphasize group activities designed in part to facilitate the acquisition of collaborative skills of the sort that are often required within contemporary work environments. Such group activities may offer students of varying ages and ability levels, and having different interests and prior experience, the opportunity to teach each other—a mode of interaction that has been found to offer significant benefits to both tutor and tutee. Explicit attention is also given to the cultivation of higher-order thinking skills, including "meta-level" learning—the acquisition of knowledge about how to learn, and how to recognize and "debug" faulty mental models.

It would be misleading to suggest that the educational research community is unanimous and unambivalent in endorsing the principles and practice of constructivism without qualification. Some[37] have argued, for example, that project-based learning techniques may be best suited to highly qualified, highly motivated teachers, and that the extensive use of these techniques by other educators may prove disappointing. Others[38] have raised concerns about the elimination or profound de-emphasis of externally assigned, linearly sequenced instructional content (textbooks, lectures, and conventional audiovisual materials, for example), pointing out that the authors and conveyors of

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[36] The centrality of such inquiries is captured in the conviction expressed by Andee Rubin, a researcher at TERC, that "education is at its very core about being curious, and about knowing how to satisfy curiosity in such a way that, as the day follows the night, more curiosity results." (Written submission to the Panel, 1995.)

[37] See, for example, Glennan and Melmed, *Fostering the Use of Educational Technology*, p. 71.

[38] This issue has been raised, for example, by Professor Robert Stevens, of Pennsylvania State University, who agrees with some of the central principles of constructivism and supports the (non-exclusive) use of project-based learning, but questions whether such techniques should form the basis for *all* aspects of K-12 education. (Private communication, 1995).

such content have often devoted considerable attention to the choice of a presentation order they believe is likely to facilitate understanding.

However compelling we may believe the argument in favor of constructivist practice to be, and however plausible we may find its theoretical underpinnings, the proposition that constructivist techniques, as currently understood, will in fact result in more favorable (in some sense) educational outcomes must still be regarded as largely (though not entirely) a collection of exciting and promising hypotheses that have yet to be rigorously confirmed through extensive, long-term, large-scale, carefully controlled experimentation involving representative student populations within actual schools.[39] While the foundations of constructivism provide a rich source of plausible and theoretically compelling hypotheses, the fact remains that the question of how best to teach our children remains an *empirical* question that has not yet been fully answered.

While the Panel is thus unable to make a confident and definitive statement regarding the superiority of the constructivist approach,[40] it believes there to be a high *likelihood* that many or all of the essential elements of this approach could play a major role in improving the quality of our nation's elementary and secondary schools. Although technology is likely to find use within a number of more traditional instructional roles as well, it seems likely (though not yet certain) that the student-centered constructivist paradigm may ultimately offer the most fertile ground for the application of technology to education.

In order to optimally cultivate this ground, schools will need to make changes that extend far beyond the mere installation of a network of computers. While some benefits may be obtained by using information technologies to pursue existing curricular objectives or by adding new material to an existing course, the richest harvest is likely to accrue from a fundamental restructuring—at least at the level of the individual course, and ideally, across disciplinary boundaries

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[39] This observation should not, however, be taken as a rationale for accepting the pedagogic status quo within our nation's schools, or for halting the progress of educational reform efforts that seek to employ technology within a constructivist framework pending the completion of such long-term experiments.

[40] This issue is, however, addressed further within the discussion of research and evaluation that appears as Section 8 of this report.

as well. Such fundamental restructuring, however, is likely to prove complex, difficult, expensive, and time-consuming, and may encounter resistance from parents, educators, and the general public, particularly to the extent that such changes conflict with commonly held beliefs about the nature of knowledge and learning.

## *4.3 Constructivist Applications of Technology*

Within the constructivist paradigm, information technology is not typically used to orchestrate the instructional process in a strictly "top-down" manner, but rather serves largely to facilitate student-initiated and mixed-initiative projects, inquiries, explorations, and problem-solving activities. By way of example (and without any attempt at comprehensiveness), computers and networks might be used within a constructivist framework to implement:

- an environment for the simulation of any of a wide range of devices and machines, physical systems, work environments, human and animal populations, industrial processes, or other natural or artificial systems
- an information retrieval or database search engine capable of extracting information from a single system or from sites distributed across the global Internet
- a tool for the symbolic manipulation or graphical display of mathematical functions, equations, and proofs
- a facility for the collection, examination and analysis of statistical data (which might be used in connection with any of a wide range of experimental or survey applications)
- a word processing, document preparation, or outlining system
- an environment for domain-specific problem-solving
- a vehicle for various forms of interactive exhibits and demonstrations
- an environment for the facilitation of group collaboration

- a flexible laboratory instrument supporting the collection of scientific data from various physical sensors and the flexible manipulation of this data under student control

- a general or application-specific numerical spreadsheet

- a "digital workbench" for the creation of musical, artistic, and other creative works

- a user-friendly environment for the acquisition of basic programming and system design skills

- a computer-aided engineering workstation supporting the design of mechanical or electrical devices, architectural projects, or even organic molecules

- an interactive hypertext encyclopedia incorporating various forms of multi-media illustrations, and supporting the rapid traversal of cross-reference links, or

- a medium for communication with teachers, parents, community members, experts, and other students, both locally and over great distances, and for the organization and coordination of group projects

## *4.4 The Human Element*

If computers are destined to play an increasingly important role in education over the next 20 years, it is natural to ask what roles will be played by human beings. Although it seems clear that the expanded use of technology in education will have significant implications for teachers, students, parents, and community members, there is reason to believe that interpersonal interactions among all these groups will be at least as important to the educational process of 2017 as they are in 1997. Indeed, the changing nature of these interactions is probably as central to the promise of new educational technologies as the hardware, software, and curricular elements outlined above.

The use of technology within the framework of the constructivist paradigm is likely to have important implications for the day-to-day role of the teacher. When a high school student using the Internet to complete a self-directed project is able to quickly gain greater familiarity with the particular subject area in question than her teacher, for example, the teacher's traditional role as a font of knowledge is likely to become less relevant. Because different students may be conducting different inquiries at any given point in time, this traditional role may be supplanted in part by one in which the teacher spends a considerable amount of time monitoring the activities of individual students (in part by wandering around the classroom and looking at their computer screens), helping them to "debug" their emerging "mental models," and providing encouragement, direction and assistance as needed.

And what about the students? Will their increasing use of educational technologies deprive them of the opportunity to develop important interpersonal and social skills? Available evidence suggests that this should probably not be a source of concern. First, it seems unlikely at this point that the students in a well-designed technology-rich school environment will spend most of their time sitting in front of their computers. When one research group provided essentially unlimited computer access to each student in a number of experimental classrooms, for example, it found that students spent an average of approximately 30 percent of their time at the computer.[41]

Moreover, this research group observed a significant *increase* in the degree of interpersonal interaction when technology was introduced into the classroom, reporting that the computers typically served as the focal point for extensive collaborative activities, and that students frequently approached each other to exchange ideas, and called each other over to show off what they had done and explain how they had done it.[42] Software can also be specifically designed to teach collaborative and cooperative skills, and to support group projects and learning exercises. In short, any fears we might have that the increasing use of computers in education will produce a generation of isolated nerds would seem to be unsupported by currently available evidence.

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[41] David Dwyer, "Apple Classrooms of Tomorrow: What we've learned," *Educational Leadership* 51 (1994), pp. 4-10.

[42] Robert J. Tierney, Ronald Keiffer, Laurie Stowell, Laura Desai, Kathleen Whalin, and Antonia Gale Moss, "Computer Acquisition: A Longitudinal Study of the Influence of High Computer Access on Students' Thinking, Learning, and Interactions," ACOT Report #16 (Cupertino, CA: Apple Computers, Inc., 1992), p. 10.

In considering the human side of educational technology, it is also worth noting that elementary and secondary education takes place within a context that includes not only the student and teacher, but also the parents and other members of the surrounding community. Substantial evidence now exists suggesting that parental and community involvement in the educational process has a significant positive effect on educational outcomes.[43] If at least basic computing resources (perhaps based on television set-top boxes or a new generation of "network computers") and Internet connectivity could be made available within the homes of those with K-12–aged children, parents would be able to receive school announcements from teachers and administrators, to communicate more easily and frequently with teachers, and to otherwise involve themselves more actively in the education of their children. The cultivation of such parental involvement may be particularly important for those students whose economic or environmental circumstances would otherwise place them at increased risk of educational failure.

There is also a growing consensus that technology should be applied in such a way as to foster broader community-wide involvement in the educational process. The linking of elementary and secondary schools with research universities, public libraries, and private companies, for example, could make valuable educational resources available to both students and teachers while simultaneously building awareness within each community of the needs of its local schools. "Real-world" projects initiated by outside organizations often generate considerable enthusiasm among students, and frequently prove unusually effective from an educational perspective.

Some educators have even discussed the possibility of instituting "tele-apprenticeship" or "tele-mentoring" programs involving brief, but relatively frequent interactions between students and other community members that would be impractical in the absence of networking technologies due to travel time considerations. Conversely, high-tech schools could serve the broader community by making their computing and networking facilities available to local residents outside of school hours, or by offering state-of-the-art job train-

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43 See, for example, Dawn M. Snodgrass, "The parent connection," *Adolescence* 26 (1991), pp. 83-77; and Illinois State Department of Education, "The Relationship Between Parent Involvement and Student Achievement: A Review of the Literature," (Springfield, IL: March 1993).

ing or lifelong learning programs tailored to community members, thus amortizing infrastructure costs over a larger effective user base while helping to foster intrinsically valuable community integration.

## 4.5 How Technology is Currently Used

In examining the ways in which information technology is currently used within the schools, it is useful to distinguish between efforts that attempt to teach students *about* computers and those that *use* computers to teach things that may or may not have any relation to technology. While basic "computer literacy" will indeed be important for twenty-first-century Americans, and while computer science, computer engineering, computer programming, and computer networking are all important areas of study, the Panel has concerned itself only incidentally with issues related to teaching *about* information technology. Rather, the focus of the Panel's investigations has been on the ways in which interactive computing and networking can be *used* at the K-12 level to facilitate learning in general.

It should be noted, however, that "computer education" currently accounts for a substantial fraction of the current use of information technologies by elementary and secondary schools. A 1992 IEA survey of school computer coordinators, for example, found that some 41 percent of the use of computers by American K-12 students involved the acquisition of keyboarding skills; instruction in the use of word processing, database management, spreadsheet, and other software tools; and the study of computer programming. Academic subjects (defined to exclude vocational instruction) accounted for 54 percent of all usage at the elementary school level, but only 31 percent within the nation's high schools.[44]

At the elementary school level, computers are often employed for teaching isolated basic skills and for playing educational games. Word processing is used to a significant extent at all levels, but in most cases as part of an effort to teach computer skills, and not as a tool for writing in connection with English, social

[44] Data from IEA Computers in Education Study, 1992, as analyzed by Becker (*Analysis and Trends*, Table 4.1).

studies, or other academic classes.[45] The situation would appear to be similar in the case of spreadsheet use, which is generally treated as an aspect of computer literacy, and less commonly integrated into, for example, the math or science curriculum.[46] It should be noted that some schools have, in fact, integrated computers extensively and effectively within many aspects of the learning process, in many cases relying on information technology as an essential element of educational reform. Such schools, however, would thus far appear to represent a very small fraction of our nation's K-12 institutions.

Although less is known about the precise ways in which wide area networks are currently being used within "ordinary" American schools (as distinguished from the handful of technology leaders that have received special attention within the educational technology community, and in some cases, in the general media), the 1995 NCES survey provides some interesting indications. Among schools with access to the Internet (about half of all public schools as of fall 1995), the most popular application is electronic mail, which is available in 93 percent of all such schools. While e-mail is generally available to administrators and (to a somewhat lesser extent) teachers, however, the majority of all schools with Internet e-mail capabilities do not make this facility available to students.

A majority of such schools also have access to Internet news groups, resource location applications (such as Gopher, Archie, and Veronica), and World Wide Web browsers (such as Mosaic, Netscape Navigator, or Microsoft's Internet Explorer). Once again, however, such applications are more commonly accessible to teachers and administrators than to students.[47] Little quantitative data is available at present about the frequency with which the Internet is used by the schools to access different sorts of information resources stored on remote sites. It seems clear, however, that the realization of its full potential for pro-

[45] The 1992 IEA survey found that even where word processing software is used to prepare written work for an academic class, such assignments are often composed using a pencil and paper, then transcribed on the computer for presentation to the teacher. Such writing was also found to be largely a solitary activity, with very little use of the computer to facilitate collaborative activities. (IEA survey data, as analyzed and reported by Becker, *Analysis and Trends*, p. 42-43.)

[46] Becker, *Analysis and Trends*, p. 71.

[47] NCES, *Advanced Telecommunications*, p. 13.

viding K-12 students and teachers with access to text, images, and audio material now held by libraries, museums, and other institutions will await the digitization of a much larger fraction of the wealth of information now available only in other forms.[48]

## *4.6 The Educational Software Market*

There is widespread agreement that one of the principal factors now limiting the extensive and effective use of technology within American schools is the relative dearth of high-quality computer software and digital content designed specifically for that purpose. While this problem is encountered by educators at all K-12 levels, it would appear to be particularly severe within our nation's secondary schools, which typically demand a broader diversity of instructional content.

Growth in the traditional ILS market, which has historically been quite robust, has recently begun to level off, leading to cutbacks in internal research and development spending by the manufacturers of such systems. Unfortunately, these cutbacks are occurring at a time when changing educational goals and a reformist emphasis on higher-order thinking skills are posing new challenges for educational software manufacturers that will be difficult to meet without such R&D expenditures. A number of major ILS vendors have been unable to justify such expenditures in light of various problems (discussed below) that they perceive within the market.[49]

The commercial availability of software and information resources designed to support student-centered, constructivist approaches to education is even more limited, and there is little evidence to date of large-scale, well-funded efforts by either traditional educational software vendors, multimedia developers, or

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[48] A number of observers have taken note of the fact that a significant collection of such materials is currently under the stewardship of the federal government. While these resources may well represent a repository of considerable potential value to our nation's schools, it should be noted that the cost of converting more than a limited subset of these materials to digital form is likely to be quite substantial, and that the conversion of even such a subset will require a nontrivial one-time investment of public and/or private sector funds.

[49] James Harvey, *The Market for Educational Software* (Santa Monica, CA: RAND Corporation, 1995), p.7.

textbook publishers to develop such content.[50] Moreover, in spite of a general appreciation of the potential for long-term growth in the market for educational software, there has thus far been only limited activity within the venture capital community aimed at launching startup companies focused on the provision of software designed for such pedagogic approaches, and targeted specifically at the nation's elementary and secondary schools.

A rather long and superficially disparate list of factors has been advanced to account for the current problems within the K-12 educational software market. The Panel believes, however, that most of these problems may be best regarded as arising largely from one or more of the following five underlying factors:

- **Inadequate software acquisition budgets.** Estimates of 1995 school expenditures for instructional software range from $470 million to $724 million,[51] representing between $10 and $16 per student-year, or less than one-third of one percent of all educational expenditures. If technology is to play a significant role in improving the quality of American education, this figure will have to be increased very substantially. Assuming no (inflation-adjusted) increase in total spending, priorities will have to be altered to allow funds now committed to other budget categories to be redeployed—a process that is complicated in many states and school districts by various statutory and procedural constraints. In the absence of such a reallocation, software developers may not find adequate incentives to justify the substantial research and development expenditures that will be required to produce a new generation of school-based educational software products.

- **Market fragmentation.** The market for school-based instructional software encompasses a wide range of academic subject areas (particularly at the secondary school level) and grade and skill levels. While this inherent diversity is arguably no greater (relative to the

[50] An important exception, however, lies in the area of software *tools* applicable not only to education, but to other activities as well. The commercial markets for spreadsheets and word processors, for example, are already well developed, while high-quality "Web browsers," "search engines," and other Internet navigation tools are being developed at a rapid pace within the private sector. While such tools are likely to play an important role within a constructivist educational framework, the Panel sees little need for federal involvement to ensure the health of these markets.

[51] Software Publishers Association (SPA), Education Section, *SPA K-12 Education Market Report* (Washington, D.C.: Software Publishers Association, 1995), p. 40, 88-91; Harvey, *The Market for Educational Software*, p. 3.

size of the potential market) than is found in various other software markets, the market for school-based educational software market (in contrast with the more robust market for home-based "edutainment" software) is further fragmented by idiosyncratic differences among the product specifications and other requirements imposed by the various states and school districts. Although it may not be feasible (for political reasons, among others) to eliminate these idiosyncratic requirements or to substitute a universally applicable set of national standards, federal guidance in the promulgation of standards could play a significant role in minimizing this potentially avoidable form of market fragmentation, providing incentives for private firms to develop software targeted toward a smaller set of more substantial submarkets.

- **Lack of modern hardware in schools.** Although America's roughly 50 million K-12 students would seem to represent a very attractive market for software developers, the effective size of this market is at present constrained by the limited size of the current installed base of hardware, and by the age of much of the equipment that *is* currently installed. Since effective market size is a critical determinant of private sector investment, the limited penetration of state-of-the-art hardware has thus far impeded research and development activities that might otherwise have led to more and better educational software products.[52] Unfortunately, this leads to a certain circularity: While software vendors are reluctant to develop products in the absence of a substantial base of modern hardware on which to run them, educators and policy-makers are reluctant to appropriate additional funds for the acquisition, maintenance, and timely replacement of hardware in the absence of a demonstrably effective base of educational software. As discussed in Section 9, the federal government may be well positioned to play a catalytic role in breaking this cycle.

- **Procurement-related problems.** The procedures used by various states to acquire textbooks and other educational materials are in many cases poorly suited to the acquisition of computer software

[52] Although an unusual *diversity* of hardware platforms has been cited as a further problem, after adjusting for the obsolescence factor—an important adjustment, to be sure—it is not clear that the installed hardware base within U.S. schools is in fact any more diverse than that of certain other relatively healthy software market segments, including graphic design, digital audio processing, various scientific and engineering specialties, and certain publishing applications.

and digital information resources. This is a particular problem in the 22 "adoption" states (primarily in the southern part of the country and in California), in which textbooks and other instructional materials must be approved by the state prior to consideration for adoption by individual districts and schools. Such approvals are often granted only once every five or more years—a considerable period within the rapidly changing software industry. Applying for approval within all adoption states can also be quite expensive. Each such state may charge an application fee of as much as $5,000 for each product to be considered for adoption, and many require that a number of computers be made available at the expense of the developer for state-level testing. In some states, the procurement process is further complicated by unusual (by private sector standards) mandated payment terms, or by well-intentioned "equity pricing" rules that, when applied to computer software, compel the vendor to charge the same license fee to each school, regardless of the number of enrolled students.

- **Innovation-related economic externalities.** As noted above, a substantial investment in research and development is likely to be necessary if effective educational software—and in particular, software supporting new pedagogic approaches of the sort recommended by many experts—is to be made available to the schools. Economic theory predicts, however, that private firms will systematically underinvest (relative to an optimal aggregate industry-wide level) in research and development to the extent they are unable to capture the full benefit accruing from any such activities that might ultimately prove successful.[53] Because innovations in educational software constitute a form of intellectual property that cannot be fully appropriated by any one firm (since the marketing and use of innovative software inevitably results in the dissemination of information of value to competitors), an economically optimal level of research is likely to be conducted only in the presence of public funding at the highest level of taxing authority (the federal government, in the case of the United States). While federal funding (especially in the form of grants provided by the National Science Foundation) has already been used to develop promising new types of software for use in math and science education, a considerably higher level of research

[53] This phenomenon represents a type of market failure arising from a particular form of economic externality sometimes referred to as the "free-rider problem."

will be required even in those subject areas to compensate for this form of market failure, while funding in the language arts, social studies, the creative arts, and other content areas has thus far been minimal.

# 5. Teachers and Technology

As schools continue to acquire more and better hardware and software, the benefit to students increasingly will depend on the skill with which some three million teachers are able to use these new tools. In order to make effective use of educational technology, teachers will have to master a variety of powerful tools, redesign their lesson plans around technology-enhanced resources, solve the logistical problem of how to teach a class full of students with a smaller number of computers, and take on a complex new role in the technologically transformed classroom. Yet teachers currently receive little technical, pedagogic or administrative support for these fundamental changes, and few colleges of education adequately prepare their graduates to use information technologies in their teaching. As a result, most teachers are left largely on their own as they struggle to integrate technology into their curricula.

## 5.1 *What Teachers Need*

Among teachers who report having one or more computer systems readily available at school, only 62 percent use a computer regularly for instruction.[54] Moreover, when teachers do make use of information technologies, they are often used for either teaching students *about* computers or for drill and practice sessions focusing on the acquisition of isolated basic skills, as noted in Section 4.5. The more ambitious and promising pedagogic applications of computers discussed in Section 4.3 call for considerably more skill from the teacher, who must select appropriate software, effectively integrate technology into the curriculum, and devise ways of assessing student work based on potentially complex individual and group projects. Not surprisingly, most teachers report that computers initially make their job more difficult.[55] Despite the daunting challenge of using computers and networks appropriately within an educational

[54] National Education Association (NEA), *Status of the American Public School Teacher 1990-91* (Washington, D.C.: National Education Association, 1992), p. 54.

[55] Martha S. Wiske, et. al., *How Technology Affects Teaching* (Cambridge, MA: Harvard Graduate School of Education, Educational Technology Center, March 1988), pp. 38-39.

context, however, teachers commonly report that they have not received adequate preparation in the effective use of computers within the classroom.[56]

Part of the problem arises from the fact that school districts frequently purchase hardware and software without allocating sufficient funds to help teachers learn to use the new equipment within an educational context. Although a consensus is emerging that school computers are likely to be underused or poorly used if less than 30 percent of the computer technology budget is allocated to professional development,[57] a 1993 survey by Market Data Retrieval found that only 15 percent of the typical computer systems budget is in fact devoted to staff instruction.[58] The State of Florida has addressed this disparity by requiring that recipients of its educational technology grants set aside at least 30 percent of all grant funds for staff development.[59] The Panel believes that similar provisions should be considered for incorporation in applicable federal programs, and that the Administration should assume a leadership role in encouraging other states and localities to do the same.

When teachers do receive instruction on the use of new technology, the form and content of the courses leave much to be desired. According to one survey, 46 percent of all educational technology courses are given as half-day workshops, and 79 percent of these courses focus on hardware, Internet usage, or a specific piece of software.[60] Teachers often have a negative reaction to the narrowly technical orientation of most technology-related courses, which show them how to *operate* a computer, but not how to use computers to enhance

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[56] Office of Technology Assessment (OTA), *Teachers and Technology: Making the Connection* (Washington, D.C., 1995), p. 129.

[57] Indeed, the optimal percentage may be considerably higher. Becker, for example, urges a *reversal* of the ratio, estimating that 30 percent of a district's technology budget should be spent on hardware and software, with the remaining 70 percent devoted to staff development and other forms of personnel support, including technology coordinators, time reserved for teachers to redesign their lesson plans, and a reduction in class size. See Henry Jay Becker, "A Truly Empowering Technology-Rich Education--How Much Will It Cost?" *Educational IRM Quarterly* 3 (1993), pp. 31-35.

[58] Market Data Retrieval, *Education and Technology, 1993: A Survey of the K-12 Market* (Shelton, CT: MDR, 1993), p. 11.

[59] "A Technology-Ready State," *Electronic Learning* 13 (1993), p. 58.

[60] Jessica Siegel, "The State of Teacher Training," *Electronic Learning* 14 (1995), pp. 44, 48.

their *teaching*.[61] Returning to the classroom from what are typically semi-annual encounters with such courses, they are generally unprepared to handle the diverse logistical and curricular challenges they encounter within a technology-rich environment.

In the Panel's view, what teachers actually need is in-depth, sustained assistance as they work to integrate computer use into the curriculum and confront the tension between traditional methods of instruction and new pedagogic methods that make extensive use of technology. Such assistance should include not only purely technical support, but pedagogic support as well, ideally including observation within the classrooms of successful technology-using teachers, periodic consultation with more experienced mentors, and ongoing communication with other teachers grappling with similar challenges.

## *5.2 Potential Modes of Support*

One particularly important resource for the development of teacher expertise in the use of educational technologies is on-site assistance from a full-time computer coordinator. Less than five percent of all schools, however, have such a full-time professional on staff.[62] Moreover, computer coordinators spend over half their time teaching students and only twenty percent of their time helping teachers, selecting software, or writing lesson plans.[63] Most teachers, however, cannot use computers effectively unless someone is available to help not only with the technical problems that are likely to arise from time to time, but also with the deeper pedagogic challenges of choosing software, organizing projects that make use of technology, and learning how to guide students in the use of computer-based resources.

If a school cannot afford to hire a full-time technology coordinator to assist its teachers, it may be possible to provide adequate (though perhaps suboptimal)

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[61] OTA, *Teachers and Technology*, p. 137

[62] Elisabeth A. Palmer, "Teacher Use and Support," in *Computers in American Schools: An Overview*, ed. Ronald A. Anderson (Minneapolis, MN: International Association for the Evaluation of Educational Achievement, 1993), p. 51.

[63] Palmer, "Teacher Use and Support," p. 52.

technical and pedagogic support at the district level. The 153 schools in Jefferson County, Kentucky, for example, are served by a Computer Education Support Unit staffed by 22 professionals who maintain a technical support hotline and work directly with teachers to encourage and improve the use of technology in the classroom.[64] Another option is to intensively train several teachers at each school who can then function as a source of expertise for their colleagues. It should be noted, however, that the provision of such training and assistance will take time away from the other responsibilities of these teachers—an implicit cost that should be realistically assessed in comparing the alternatives for providing technological support to the rest of the faculty.

Cause for optimism, however, may be found in certain contributions that technology itself may ultimately make to the development of expertise in the educational applications of computers and networks. First, the Panel expects that over time, educational software will evolve in such a way as to make less extensive demands on the teacher. In this regard, it is worth noting that the dissemination of computer usage through progressively broader segments of the population has historically been less a function of increasing technical expertise within the general population than of the development of software that *requires* less technical expertise. Ongoing improvements in processing speed, memory capacity, user interface design, and educational applications can be expected to result in software that both teachers and students can use with less training, and more extensive support for curricular integration is likely to be provided within the application package itself.

Information technology may also help teachers to recover at least some of the time they have invested in deploying technology on behalf of their students. Some (though certainly not all) types of educational software, for example, may ultimately enable students to spend part of the school day learning with less continuous attention from a teacher.[65] Computing and networking technologies also have the potential to streamline many aspects of a teacher's daily responsibilities, facilitating the development of instructional materials, the re-

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[64] OTA, *Teachers and Technology*, pp. 147-149.

[65] Henry J. Becker, *Analysis and Trends of School Use of New Information Technologies*, report prepared for the Office of Technology Assessment, U.S. Congress, 1994, pp. 88-89.

cording and assessment of student progress, and access to various forms of information resources.[66]

In addition, technology may ultimately play a *direct* role in supporting the professional development functions discussed in this section. It has been estimated, for example, that online seminars conducted over the Internet might prepare teachers to use technology at roughly half the cost of conventional courses for which the teachers must be physically present,[67] and equally important, might make it feasible to provide opportunities for followup consultation and mentoring on an *ongoing* basis without the prohibitive travel expenses that would be associated with repeated face-to-face meetings. The Internet also provides an excellent medium for various forms of communication among teachers themselves, including the sharing not only of ideas, but of actual lesson plans and curricular materials as well.

## 5.3 The Problem of Insufficient Teacher Time

If teachers were given adequate instruction in the art of computer-enhanced pedagogy and had access to on-site assistance as needed, they would be in a better position to reap the benefits of educational technology, but one major obstacle would remain: a lack of sufficient time in their schedules to become familiar with available hardware, software, and content; to prepare technology-related material for use in the classroom; and to share ideas on technology use with other teachers.[68] In a 1989 survey of 600 fourth- through twelfth-grade teachers conducted by the Center for Technology in Education, respondents indicated that whereas high student/computer ratios had posed the most significant barriers to the effective use of educational technology in the past, the

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[66] Barbara Means and Kerry Olson, *Technology's Role in Education Reform: Findings from a National Study of Innovating Schools* (Menlo Park, CA: SRI International, September 1995), p.16-20.

[67] Robert Tinker, in discussion at a meeting of the PCAST Panel on Educational Technology, 1995.

[68] The development of high-quality courseware is a difficult, time-consuming, and intellectually challenging process under the best of circumstances; when such responsibilities are combined with the mastery of an entirely new set of technological tools, it may prove difficult for even the most competent and dedicated teachers to find the time for such activities.

greatest *current* obstacle was a lack of sufficient time to develop lessons that *use* computers.[69]

On average, teachers have only ten minutes of scheduled preparation time for each hour they teach.[70] Since this is generally insufficient to adequately prepare for their classroom responsibilities, they typically spend additional hours outside the school day preparing lessons and grading student work, resulting in an average of 47 hours of work per week.[71] Given such schedules, most teachers find it extremely difficult to reshape their teaching on an ongoing basis around a rapid series of technological innovations.[72]

While some of the technology available to teachers—application packages designed to provide assistance with various administrative, record-keeping, and student assessment tasks, for example—may free up a certain amount of time, this effect is unlikely to offset the additional time required to effectively utilize computers on an ongoing basis. Estimates formulated by various researchers[73] suggest that it will take the typical teacher between three and six years to fully integrate information technologies into his or her teaching activities, and ongoing technological changes are likely to ensure that the learning curve never levels off completely. Unless additional time can be made available through the elimination or de-emphasis of other, less critical tasks, such demands are likely to represent a significant ongoing obstacle to the effective utilization of educational technology.

The problem of insufficient teacher time encompasses both a logistical question (how to restructure the school day to give teachers time to develop tech-

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[69] Karen Sheingold and Martha Hadley, *Accomplished Teachers: Integrating Computers into Classroom Practice* (New York, NY: Center for Technology in Education, Bank Street College of Education, September 1990), p. 21.

[70] NEA, *Status of the American Public School Teacher*, pp. 47-48.

[71] NEA, *Status of the American Public School Teacher*, p. 46.

[72] The influence principals have over teachers' schedules constitutes one reason that principals should participate in technology-related staff development. Programs specifically designed for principals, such as Indiana's statewide Principals' Technology Leadership Training Program, can dramatically increase the administrative support that teachers receive for using new technology. (OTA, *Teachers and Technology*, pp. 153-154.)

[73] OTA, *Teachers and Technology*, p. 41; Nancy Hechinger, "*Towards a Model of Technology in Education for the 21st Century*", written submission to the Panel, p. 5; Sheingold and Hadley, *Accomplished Teachers.*

nology-related teaching skills) and an economic question (how to pay for the additional time associated with technology-related professional development and class preparation). To illustrate the magnitude of the latter challenge, if all of our nation's public K-12 schools were to set aside two hours per week for technology-related curriculum design, as is the case in Arizona's Agua Fria Union High School,[74] technology-related educational expenditures would increase by about $9 billion per year—more than *tripling* by comparison with current spending levels.[75] Although technology itself may help to mitigate these problems, the (direct and/or opportunity) cost of the time that will be required for teachers to incorporate technology effectively within the curriculum will present a significant challenge—particularly during an initial transition period—to the effective utilization of educational technologies.

## 5.4 Technology in the Education Schools

Over 200,000 new teachers enter the profession each year, and there is a 50 percent turnover in the teaching force approximately every 15 years.[76] While advances in underlying technologies, educational software, and pedagogic methods will result in an ongoing need for in-service training, colleges of education have a valuable opportunity to introduce future teachers to the use of educational technology before the demands of an actual teaching position begin to impinge on the time available for such training.

Judging solely from teacher certification requirements in the various states, it would at first appear that education students receive more technology-related instruction than do active teachers: Eighteen states require pre-service technology training, while only two require in-service technology training.[77] Pre-service requirements, however, can typically be satisfied by completing a course

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[74] Siegel, "The State of Teacher Training," p. 48.

[75] This example is presented for illustrative purposes only; as discussed in Section 6, experts in fact differ significantly on the magnitude of the professional development requirements that will be imposed by the introduction of technology into America's schools.

[76] Derived from: U.S. Department of Education, National Center for Education Statistics (NCES), *Projections of Education Statistics to 2006*, 25th Edition (Washington, D.C., March 1996); NCES, *America's Teachers: Profile of a Profession* (Washington, D.C., May 1993); and NEA, *Status of the American Public School Teacher.*

[77] OTA, *Teachers and Technology*, pp. 120-121, 175.

on how to *operate* a computer, or by taking a "methods" course in which educational technology is discussed, but never actually used by either the professor or the students. As a result, even in states with a technology-related certification requirement, new teachers typically graduate with no experience in using computers to teach, and little knowledge of available software and content. The Office of Technology Assessment summarized the current situation concisely: "Overall, teacher education programs in the United States do not prepare graduates to use technology as a teaching tool."[78]

Colleges of education fail to instruct their students in the use of educational technology for reasons that mirror some of the major obstacles to the spread of technology at the K-12 level, including the inadequate allocation of funds for hardware and software, minimal technology-related professional development for the education school faculty, and a lack of time for professors of education to restructure their courses. Education schools generally have the advantage of better technical support (often provided through the campus computer center) than elementary and secondary schools, but research, publishing, and other academic responsibilities place additional demands on the faculty, thus slowing the process of curricular reform.[79]

The Panel believes that the principal focus of an education school's technology program should be the ways in which elementary and secondary school teachers can use information technologies to facilitate thinking and learning by K-12 students. Nonetheless, given that K-12 teachers will find it difficult to help their students make effective use of computing and networking technologies if they have gained little experience doing so themselves, *any* element of the education school curriculum that affords prospective teachers the experience of making profitable use of information systems is likely to increase the probability of effective later use within a professional context. Colleges of education should be encouraged to find ways to reward faculty members who include new technologies in the methods or content of their courses. Specialized degree programs in educational technology should also be encouraged, both to address the need for computer coordinators capable of providing teachers with more

[78] OTA, *Teachers and Technology*, p. 184.

[79] OTA, *Teachers and Technology*, pp. 184, 187-191.

than purely technical support and to foster the development of a nucleus of technological expertise within the education faculty.[80]

Education students should also be given the opportunity to observe the use of educational technology and to practice teaching with technology in K-12 schools. If the elementary and secondary schools that are available for student teacher placement have not yet effectively integrated technology into their own curricula, education students may be able to obtain some (though certainly not all) of the same benefit by studying examples of technology-rich pedagogy on videotape or interactive videodiscs. Indeed, such materials may be useful even when technology-rich placements are available, since they may enable education students to analyze complex classroom events more closely than would be permitted by real-time observation. Repeated viewings and discussions of particular teacher-student interactions, supplemented by exercises in which the video is stopped and education students are asked what *they* would do, can yield considerable insight into essential issues involved in effective technology use.[81]

Funding decisions at the federal level could have a significant impact on the degree to which America's education schools are capable of producing teachers who are able to make effective use of educational technology. In the past, federal funding has not been available for pre-service teacher development at levels comparable to those associated with in-service training, and Federal support for technology-related teacher development in general has been described as "highly variable from year to year, piecemeal in nature, and lacking in clear strategy or consistent policy."[82] Federal grants targeted toward both the extensive use of modern information technologies within our colleges of education and the inclusion of educational technology as an integral part of the education

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[80] Linda C. Barron and Elizabeth S. Goldman, "Integrating Technology with Teacher Preparation," in *Technology and Education Reform: The Reality Behind the Promise,*" ed. Barbara Means (San Francisco, CA: Jossey-Bass, 1994), p. 102.

[81] Barron and Goldman, "Integrating Technology with Teacher Preparation," pp. 88-95.

[82] OTA, *Teachers and Technology*, p. 208.

school curriculum would go a long way toward insuring that America's future teachers are able to provide the next generation of Americans with the best possible education.

# 6. Economic Considerations

While funding by no means represents the only challenge that will have to be overcome if the potential of educational technology is to be realized, most of the other challenges would be far less formidable if cost were not an issue. As a result of current budgetary pressures, however, along with a persistent historical pattern of significant inflation-adjusted increases in educational expenditures, economic considerations have in fact assumed a position of central importance in the ongoing deliberations surrounding the topic of educational reform.

In this section, we compare estimates of current technology spending for K-12 education with projections of the expenditures that will likely be required in order to capture substantial benefits. We then briefly consider the potential role and likely limitations of technology in improving the *productivity* of the educational enterprise, and end with a brief discussion of the analysis of federal education expenditures in terms of return on investment.

## 6.1 *Current Technology Expenditures*

While the estimation of current annual spending on educational technology is complicated by differences in the types of expenditures included within this category by different observers, the available data suggests that public elementary and secondary schools in the United States spent somewhere between $3.5 and $4 billion on computing and networking hardware, wiring and infrastructural enhancements, software and information resources, systems support, and technology-related professional development during the 1995-96 school year.

A study conducted by McKinsey & Company for the National Information Infrastructure Advisory Council[83] put the corresponding figure at approximately $3.3 billion during the 1994-95 school year, including expenditures of about $1.4 bil-

[83] McKinsey & Company, Inc., *Connecting K-12 Schools to the Information Superhighway,* report prepared for the National Information Infrastructure Advisory Council, (Palo Alto, CA: McKinsey & Co., Inc., 1995), p. 66.

lion for hardware,[84] $800 million for software and other content,[85] $500 million for local interconnection,[86] $200 million for wide-area networking,[87] $300 million for professional development,[88] and $100 million for systems operation.[89] These McKinsey estimates appear to be in rough agreement (after adjustment for differences in included expense categories) with those reported by several other researchers,[90] and have been adjusted upward to account for what would appear to be a relatively rapid current growth rate in arriving at our estimates for 1995-96.

The McKinsey estimate of $3.3 billion in technology-related expenditures during the 1994-95 school year represents only 1.3 percent of the roughly $248 billion[91] that was spent during that period on public K-12 education (excluding capital outlays, debt service, and state administrative costs). Expressing these aggregate numbers in more familiar terms, of the $5,623 our public schools spent during the 1994-95 school year[92] on each of the 44 million students[93] who were enrolled as of the beginning of that year,[94] just $75 was allocated to tech-

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[84] Based on data and estimates provided by QED, Apple Computers, Paul Kagan, SPA/CCA Consulting, Peter Li, and Anne Wucjik & Associates.

[85] Based on data and estimates provided by Peter Li, Anne Wucjik, and the SPA.

[86] Based on data provided by the SPA and estimates by McKinsey.

[87] Based on estimates by McKinsey.

[88] Estimated by McKinsey (based on case studies and interviews) at 10 percent of total educational technology expenditures; Market Data Retrieval, on the other hand, puts this figure at 15 percent, as noted in Section 5.1, footnote 58.

[89] Estimated by McKinsey (based on case studies and interviews) at five percent of total educational technology expenditures.

[90] See, for example, SPA, *K-12 Education Market Report*, pp. 61-62; Peter Li Education Group and Anne Wujcik & Associates, as cited in McKinsey, *Connecting K-12 Schools*, p. 66; Thomas K. Glennan and Arthur Melmed, *Fostering the Use of Educational Technology: Elements of a National Strategy*, the RAND Corporation, 1996, p. 38; and Benton Foundation, *The Learning Connection*, <http://www.benton.org/Library/Schools-/connection.html>, 1996.

[91] Computed based on data reported by the U.S. Department of Education, National Center for Education Statistics (NCES), *Digest of Education Statistics* 199 (Washington, D.C., 1995), p. 163.

[92] NCES, *Digest of Educational Statistics*, p. 163.

[93] As estimated by state education agencies and reported in NCES, *Digest of Educational Statistics*, p. 53.

[94] Based on ratios observed in earlier years (NCES, *Digest of Educational Statistics*, p. 50), however, this statistic may be assumed to overstate the average daily attendance figures actually experienced during the 1994-95

nology-related expenditures. While a number of complex issues arise in the course of comparing educational institutions with private sector enterprises, it seems clear that our public schools allocate a considerably smaller share of their financial resources to computer and networking technologies than do most information-based industries.

## 6.2 Projected Cost of Educational Technology

Estimates of the cost of introducing information technology into U.S. classrooms and effectively using such technology to improve the quality of American education vary widely, in large part as a result of differences in assumptions regarding the level and nature of technology usage and the provisions made for technology-related professional development. After adjustment for these factors, however, the projections of most observers are reasonably consistent, and provide a basis for assessing the magnitude of the funding that would be required to have a meaningful impact on our nation's schools.

In the McKinsey/NIIAC study, cost projections were formulated for models based on four different levels of technology usage. The lowest level, which assumed an average of 25 computers per school, all deployed within a single Internet-connected computer lab or multimedia room, was estimated to involve an initial acquisition cost of $11 billion nationwide, with an additional $4 billion per year required for operation and maintenance. Adding a computer and modem for every teacher was projected to double the initial deployment cost and increase ongoing operating expenses to $7 billion. A model in which networked computers are installed in half of all classrooms (at a density of one computer for every five students), and the central lab is eliminated, was estimated to entail $29 billion in initial costs and $8 billion per year for operation and maintenance. A similar model in which computers are deployed in *all* classrooms (at the same one-to-five ratio) was estimated to require $47 billion initially and annual operating expenses of $14 billion.[95] A percentage break-

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school year by an estimated eight percent. Both the overall and technology-related expenditures cited here would thus have to be scaled upward (though by a comparable factor) to obtain a realistic estimate of the resources actually deployed on behalf of each student.

[95] McKinsey, *Connecting K-12 Schools*, pp. 20-24.

down of McKinsey's projected costs by category is shown in Table 6.1 for the lowest ("Laboratory") and highest ("Classroom") levels of technology use.

*Table 6.1*

**Breakdown of McKinsey/NIAAC Cost Projections**[96]

| *Cost Category* | *Laboratory Model* | | *Classroom Model* | |
|---|---|---|---|---|
| | *Initial* | *Annual* | *Initial* | *Annual* |
| Hardware | 34% | 17% | 51% | 14% |
| Software, Other Content | 20 | 26 | 14 | 21 |
| Local Interconnection | 12 | 5 | 13 | 4 |
| Wide-Area Networking | 7 | 15 | 4 | 7 |
| Professional Development | 19 | 31 | 14 | 41 |
| Systems Operation | 8 | 6 | 4 | 13 |

A 1995 study conducted by the RAND Corporation examined six "technology leader" schools (including three of those profiled in Section 2.3) and attempted to estimate the cost of providing similar capabilities within a typical American school. Hardware and software investments were amortized over a five-year period to obtain annualized expenditure projections; equipment costs were based not on the historical cost of each school's actual inventory, but on the prices of roughly equivalent hardware as of the time of the study. Infrastructure costs were amortized over a ten-year period, while staff costs, professional development, materials and supplies were treated as ordinary (non-capitalized) expenses. Hardware and personnel costs were found to dominate other technology-related expenditures, and to account for much of the variation among

96 Adapted from McKinsey, *Connecting K-12 Schools*, Exhibit 7, p. 28.

the six model schools, whose replication costs ranged from a low of $142 to a high of $415 per student-year.[97]

To facilitate the identification of an approximate consensus range for the projected cost of introducing technology into American elementary and secondary schools, we have (somewhat arbitrarily, and at the expense of a rather Procrustean assault on some of the original data) converted the above projections, along with those of several other authors, into annualized cost figures based on the amortization of capital acquisition and other startup costs over a five-year period. The resulting figures are presented in Table 6.2.

***Table 6.2***
**Cost Projections of Various Authors**

| *Source* | *Projected Cost/Year*[98] |
|---|---|
| Glennan and Melmed[99] | $9 to $22 billion |
| Harvey[100] | $7 to $15 billion |
| Keltner and Ross[101] | $7 to $21 billion |
| McKinsey[102] | $6 to $23 billion |
| Means and Olson[103] | $23 billion |
| Moursund[104] | $14 to $28 billion |

97 Brent Keltner and Randy Ross, *The Cost of High Technology Schools* (Santa Monica, CA: RAND Corporation, 1995).

98 Various assumptions and approximations have been made in converting the projections appearing in each source document into a common form for presentation in this table. The actual projections of each author may be found in the individual source documents, which are referenced separately below.

99 Glennan and Melmed, *Fostering the Use of Educational Technology*, p. 45.

It is worth noting that none of these spending projections were prepared with an eye toward estimating the cost of deploying and using technology in a manner that would be optimal in the absence of budgetary constraints. Henry Becker[105] has attempted to realistically assess the cost of applying technology in ways that are believed by many to offer the greatest potential for truly significant improvements in educational effectiveness. Central to his analysis is an examination of "the kinds of expenditures that permit average teachers to become exemplary users" of educational technology, including a reduction in average student/teacher ratios from 25 to 20 and the allocation of sufficient resources and teacher time to allow teachers to use technology in their own professional lives. He also assumes the availability of one computer for every two students (phased in over a four-year period)—a significantly greater density than is assumed in most other models.

By way of contrast with the projections cited earlier, the ambitious undertaking outlined by Becker would entail an estimated annual cost of $1,375 per student in personnel costs, along with $556 per student-year for hardware, software, and maintenance. Although the implementation of such a model would increase average school expenditures by more than a third, he points out that such an increase would be no greater than that associated with many other proposals for fundamental educational reform, and argues that even an investment of this magnitude may be justified by the potential returns.

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[100] James Harvey, ed., *Planning and Financing Education Technology* (Santa Monica, CA: RAND Corporation, 1995), p. 7.

[101] Keltner and Ross, *The Cost of High Technology Schools.*

[102] McKinsey, *Connecting K-12 Schools*, p. 21.

[103] Barbara Means and Kerry Olson, "Technology's Role in Educational Reform," report for the U.S. Department of Education, Office of Educational Research and Improvement (Washington, D.C.: September 1995), p. 99.

[104] Dave Moursund, Talbot Bielefeldt, Dick Ricketts, and Siobhan Underwood, *Effective Practice: Computer Technology in Education* (Eugene, OR: International Society of Technology in Education, Fall 1995), p. 102.

[105] Becker, "A Truly Empowering Technology-Rich Education," pp. 31-35.

It should be noted that in the absence of a substantial advance in productivity of the sort discussed in Section 6.3, even the more moderate spending projections summarized in Table 6.2 will require an increase in the fraction of the nation's education budget that is allocated to technology-related expenditures from the current level of approximately 1.3 percent to somewhere between 2.4 and 11.3 percent. Moreover, the acquisition of computing and networking hardware—often the principal focus of efforts to bring technology into the schools—will in fact account for only a minority of the expense incurred over time. While special bond issues, private capital campaigns, and other one-time funding mechanisms may all have their place in helping schools to defray the costs of acquiring hardware, it is important that educators and policy-makers have realistic expectations regarding the ongoing operating expenditures that will be necessary if this hardware is in fact to be effectively used, and that they not base their planning on capital budgeting models of the sort used to analyze, for example, the acquisition of new school buildings.

In the absence of realistic budgetary planning, schools and school districts are prone to overspending on the initial acquisition of hardware, and may find themselves with inadequate funding for upgrading and replacement, software and content, hardware and software maintenance,[106] professional development for teachers, and the hiring and retention of necessary technical support personnel. If we do not wish to turn our schools into junkyards for expensive, but unused computer equipment—a scenario that is, unfortunately, far from uncommon at present—it is important that budgetary constraints and wishful thinking not lead us to buy the educational equivalent of a fancy automobile without allocating funds for gasoline, repairs, or a driver education class.

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[106] One proposal that is sometimes advanced for the minimization of maintenance and support costs would involve the provision of such services by students. The proponents of this approach typically argue that such activities may be valuable not only as a service to the school, but as a learning experience for the student. To the extent that such activities can in fact be justified from an educational viewpoint, the Panel would be inclined to support at least preliminary experimentation with such an approach. While student involvement in the operation of a functioning computer network may indeed offer attractive possibilities for learning, however, it is worth noting that the same argument could be made with respect to the conscription of students to maintain the school's physical plant, or to provide its administrative support. Although each of these ideas might arguably be worthy of exploration in its own right, particularly within the context of a constructivist curriculum, the Panel believes that we can no more expect the problem of technology maintenance and support to be solved exclusively through the use of student technicians than we can expect the problem of school security to be solved exclusively through the use of student hall monitors.

Although the expected tradeoff between spending and outcome renders meaningless the notion of a single "optimal" level of expenditure, the Panel recommends (based on the limited data thus far available) that at least five percent of all educational spending in the United States, or approximately $13 billion annually (measured in constant 1996 dollars), be earmarked for technology-related expenditures on an ongoing basis. It should be noted that this recommended expenditure level represents nearly a fourfold increase in the fraction of our nation's education budget that is now allocated for such purposes. If the promise of educational technology is to be realized, educators and policymakers will thus unavoidably be faced with difficult decisions as they attempt to either control or justify a secular trend of increasing (inflation-adjusted) per capita educational spending within the constraints imposed by a number of well-entrenched claimants on current financial resources.

## *6.3 Educational Productivity and Return on Investment*

While the projections summarized above provide a starting point for analyzing the likely economic implications of the widespread introduction of technology within our nation's classrooms, these estimates should be considered in the context of an important caveat: Our experience with educational technology (and in particular, with approaches to its utilization based on the constructivist pedagogic models discussed in Sections 4.2 and 4.3) is still quite limited, raising the possibility of a significant technology-related upward shift in what economists refer to as the education production function—a curve expressing some measure of educational outcomes as a function of educational expenditures—over time. Indeed, the adoption of new technologies within other industries has frequently been accompanied by an initial *decrease* in productivity, with benefits accruing only after the technology in question has been effectively assimilated—a process that often involves the introduction of significant structural changes within the adopting organization.

As we begin to ascend what is likely to be a relatively steep learning curve, however, the extent to which we are able to benefit from our experience in order to realize substantial savings in achieving a given set of educational objectives (or alternatively, to improve educational outcomes for a given spending level) is likely to depend critically on the execution of rigorous, large-scale programs of research and evaluation aimed at assessing the efficacy and cost-effectiveness of various approaches to the use of technology in actual K-12 classrooms, as discussed in Section 8 below. While the results of such research are intrinsically difficult to predict, the extremely low level of current investment in such research relative to the enormity of our nation's investment in elementary and secondary education leads the Panel to believe that we are far below the point at which the incremental cost of further research would exceed the economic benefit to which it is likely to lead.[107]

Because personnel-related costs account for the largest share of our nation's educational spending, and because the substantial increase in (inflation-adjusted) spending per student over the past several decades has been attributed in large part to a steady increase in the ratio of staff size to school enrollment, some have asked whether technology might be used to improve the economic productivity of those employed within the American educational system, as has been the case within various other sectors of the U.S. economy. In principle, such improvements might arise from a decrease in per-pupil costs attributable to the more effective "leveraging" of educators and support personnel, from the realization of improved educational outcomes for a given level of personnel-related and other expenditures, or from a combination of these and/or other factors.

In considering the potential role of technology in increasing educational productivity, it is worth noting that teachers are likely to play a critically important role within the sort of future classroom envisioned by most current researchers in the field of educational technology, as discussed in Section 4.4. While this may be a comfort to fearful teachers (and in some cases, parents), it may also be a disappointment to those who have looked to technology for a simplistic automation of the instructional function, accompanied by a wholesale reduction in our nation's aggregate expenditures on teacher compensation. Based on the models provided by other information-based industries, however, it seems quite likely that continued experimentation with technology will ultimately yield a wide range of alternatives, falling at different points along the production function curve, for the improvement of educational productivity.

[107] See Section 8.4 for a brief discussion of the rationale underlying this conjecture.

To the extent that such productivity increases are captured in the form of increased learning (according to some suitable metric) per student hour, and not by a reduction in total expenditures per student hour, the attendant benefits are best analyzed not in terms of cost alone, but in terms of expected return on investment. The empirical validation of such an analysis is complicated by the fact that the return on an educational investment is determined in large part by such factors as lifetime earnings (which will generally not be known for many decades after the investment in question is made), along with a number of non-pecuniary factors even less amenable to straightforward quantification. It seems quite possible, however, that in the presence of formidable global economic competition, a substantial nationwide investment in educational technology could be justified even if *no* value were placed on the direct (economic and non-economic) benefits accruing to the American people, using return calculations based solely on the additional tax revenues associated with an increase in their expected lifetime taxable earnings.

# 7. Equitable Access

Equitable access to information technologies in education has been a central concern of educators and policy-makers since microcomputers first entered our nation's schools some twenty years ago, but has gained special attention during a period in which powerful desktop computers and global Internet connectivity are rapidly becoming an integral part of the lives of some—but not all—American families. On the one hand, it has been frequently noted that new computing and networking technologies have the potential to empower historically disadvantaged groups of Americans with greater access to the sorts of knowledge-building and communication tools that might help them to overcome at least some of their respective disadvantages. While the Panel believes this potential can scarcely be overstated, it also believes that the ways in which educational technologies are actually deployed and used will determine whether they serve to narrow these historical disparities or widen them even further.

This section begins with a discussion of the various dimensions along which the accessibility of various technologies—both at school and within the student's home—can be usefully measured. The current accessibility of computing and networking technologies to various segments of the American student population is then reviewed, with special attention to differences associated with socioeconomic status, race and ethnicity, geographical factors, gender, and various types of special student needs. Throughout this section, consideration is given to the appropriate role of the federal government in insuring equitable (and ultimately, universal) access to educational technologies.

## *7.1 Dimensions of Access*

One metric that has been used to evaluate the extent to which educational technology is accessible to various groups is the density of computers installed within the schools attended by members of those groups. Schools with higher computer densities typically provide greater access to other forms of educational technology (including local- and wide-area networks and peripherals supporting multimedia applications) as well, making computer density a useful (albeit imperfect) proxy for the level of overall technology deployment. While the ratio of computers to students varies widely from school to school,[108] and while much of this variation is accounted for by other factors,[109] our principal concern in the current context will be with the density of computers in schools whose student bodies differ systematically along socioeconomic, racial, ethnic and geographic lines.

Equitable access, of course, depends not only on the number of computers available within a given school, but on the extent to which those computers (along with other educational technologies) are actually used by various groups and the modes of usage associated with each group. Although number of hours of student computer use—particularly within subject-matter (as opposed to computer education) classes—is strongly correlated with computer density,[110] socioeconomic and other factors have been found to have independent predictive value, as discussed below. Such variables are also predictive of the *manner* in which computers are used in school, with certain groups participating in constructivist applications of the sort described in Section 4.3 or in other "higher-order" learning and problem-solving activities while others use technology primarily for routine drill-and-practice exercises. To the extent that the former category of usage is believed to have special value in meeting the objectives of contemporary educational reform, systematic differences in the character of technology usage may be as problematic as lack of access to computing and networking hardware.

While we have thus far considered the accessibility of educational technology only within the school, systematic disparities in the availability of computers and modems within the home may represent an even greater problem from the

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[108] The 1992 IEA Computers in Education Study (as analyzed in Henry J. Becker, *Analysis and Trends of School Use of New Information Technologies*, report prepared for the Office of Technology Assessment, U.S. Congress, 1994, p. 50) found that the 20 percent of schools with the highest computer density had six times more computers per student than the 20 percent with the lowest density.

[109] School size, for example, has a particularly large impact: The smallest 25 percent of schools have nearly twice as many computers per student as the largest 25 percent—an effect Becker attributes to the fact that schools across a wide range of sizes often purchase enough (and only enough) computers for an entire class of students to use simultaneously. Becker (personal communication, 1996) has also calculated (based on data from the 1992 IEA Computers in Education Study) that public school students enjoy a 17 percent greater computer density on average than those who attend non-public schools.

[110] Becker, *Analysis and Trends*, pp. 53-54.

viewpoint of equitable access. At present, computers are found in approximately half of all American households with children,[111] and a large fraction of all children whose families do have computers at home use them regularly for school work.[112] In addition, students having access to a computer at home appear to use it for about an hour each week[113] for purposes that are at least broadly educational in nature,[114] a figure roughly equal to the typical student's computer usage in school.[115] As information technologies begin to play an increasingly central role in K-12 education, a doubling in the time available for educational computer use can be expected to confer an increasingly significant advantage on those children whose families are able to provide them with computer (and in some cases, Internet) access at home. Because certain segments of the American population have a far lower level of computer ownership than others, home access may now be one of the most significant sources of educational inequity in the United States.

## 7.2 Socioeconomic Status

Specifically targeted federal programs have in recent years helped to substantially mitigate some of the disparities in access to educational technology that had earlier been associated with socioeconomic variables. Income-related differences in computer density, for example, have been reduced to a relatively modest (though still not insignificant) level: During the 1994-95 school year,

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[111] As of June 1995, some 45 percent of all households with children under 18 years of age (but only 30 percent of all childless households) owned at least one computer, and this figure is believed to have risen since that time. (Margaret Petrella, Pew Research Center for the People and the Press, Washington, D.C., private fax communication, July 1996, based on data from 1995 survey by Times Mirror Center for the People and the Press.)

[112] By way of example, 85 percent of all teenagers whose families have computers at home report using them for school work. See Times Mirror Center for the People and the Press, *Technology in the American Household* (Washington, D.C.: Times Mirror Center for the People and the Press, May 1994), p. 28.

[113] This time estimate is based on estimates provided to the Panel by PC/Meter, L.P. (Port Washington, NY, fax communication, August 1996) and the Software Publishers Association (Washington, D.C., fax communication, August 1996).

[114] For purposes of these estimates, we have included in this category not only activities identified explicitly as educational, but also the use of reference, database, spreadsheet, web search, and "edutainment" software.

[115] Office of Technology Assessment (OTA), *Teachers and Technology: Making the Connection* (Washington, D.C., 1995), pp. 101-102.

the poorest schools (defined as those schools in which more than 80 percent of all students were eligible for funds under Title I of the Elementary and Secondary Education Act) had one computer for every 11 students, while each computer in the richest schools (those having less than a 20 percent Title I enrollment) was shared by 9.5 students.[116] By way of contrast, in 1983, microcomputers were found in *four times* as many of the 12,000 wealthiest schools as in the 12,000 poorest schools.[117]

While this progress is certainly encouraging, there are several reasons for continued concern. First, there is considerable direct and indirect evidence that the shrinkage of the gap in computer density between rich and poor schools is attributable largely to the Title I program itself, which provided roughly $2 billion in funding over the past ten years for the introduction of educational technology within schools having a substantial low-income enrollment, but which has recently been under considerable budgetary pressure.[118] Second, the relatively modest gap between the computer densities measured at richer and poorer schools belies significant disparities in the way computers are actually used in school by more and less affluent students, and in the availability of computers within their homes.

Students from families classified as low in socioeconomic status (SES) report 14 percent less usage of computers in school than do students from high-SES families.[119] Lower-SES high school students are also significantly more likely to

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116 Derived from data presented in Quality Education Data, Inc. (QED), *Technology in Public Schools*, 14th Edition (Denver, CO: Quality Education Data, Inc., 1995), p. 31.

117 QED, *Technology in Public Schools*, First Edition, Denver, CO, 1983, as cited in Ronald E. Anderson, Wayne W. Welch, and Linda J. Harris, "Inequities and Opportunities for Computer Literacy," *The Computing Teacher* 11 (1984), pp.10-12.

118 The Labor, Health & Human Services, and Education Subcommittee of the House Appropriations Committee, for example, recently voted to freeze nominal 1997 Title I spending at the 1996 level, corresponding to a nontrivial reduction after adjustment for a combination of inflation, increasing U.S. school enrollments, and projected increases in overall national spending for K-12 educational technology.

119 This figure was derived from Becker's analysis of data from the 1992 IEA Computers in Education Study (Becker, *Analysis and Trends*, p. 54, Table 6.4A), which compared the highest-SES 25 percent and the lowest-SES 23 percent of a sample of fifth-, eighth-, and eleventh-grade students according to a metric based on family ownership of various household items and (with the exception of the fifth-grade students) level of parental educational attainment. The figure we report here is actually the mean of the quantities computed separately for each grade level. If the students sampled at all three grade levels had been aggregated for purposes of this

be taught *about* computers than to *use* computers in the course of other learning.[120] Moreover, when high-SES students are exposed to computers as a subject area, they are more likely to engage in computer programming (as opposed to lower-level computer-related tasks) than low-SES students.[121] More generally, high-SES eighth- and eleventh-grade students were found to be 25 percent more likely to use computers primarily for "higher-order or mixed" activities (rather than drill-and-practice or other skill-building or knowledge acquisition activities) than low-SES students of the same grade levels.[122] To the extent that the sorts of higher-order computer activities in which high-SES students are disproportionately engaged in fact offer greater opportunities for learning,[123] such SES-related disparities in the in-school use of computers may represent a form of inequity at least as important as (even if less obvious than) SES-related differences in computer density.[124]

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calculation, the disparity in question would have been exaggerated by a rather subtle form of bias attributable to two distinct, but interacting confounders. On the one hand, average computer use is positively correlated with grade level. Another factor that is found to be positively correlated with grade level in the IEA survey data, however, is the ratio of high- to low-SES students—an effect that might be expected given the fact that the parents of 11th-grade students are presumably older and (due to economic life cycle effects) more affluent on average than those of 5th-grade students. If students were aggregated across grade levels, a portion of the calculated SES-related usage disparity would result from an artifactual correlation between SES and usage that was actually mediated by the grade level variable. This anomaly is avoided by calculating the quantity of interest separately for each grade level, then combining the results.

[120] Becker's analysis of data from the 1992 IEA Computers in Education Study, for example, revealed that high school students from low-SES families used computers 15 percent *more* than the average high-school student in computer education classes, but 13 percent *less* than average in all other classes (Becker, *Analysis and Trends*, p. 54, Table 6.4).

[121] The Office of Technology Assessment found, for example, that computer programming accounted for 30 percent of the use of computers by high-SES students, compared with only 13 percent in the case of their low-SES counterparts. See Office of Technology Assessment (OTA), *Trends and Status of Computers in Schools: Use in Chapter 1 Programs and Use With Limited English Proficient Students* (Washington, D.C., 1987), Figure 10.

[122] Derived from results presented in Table 6.6 of Becker, *Analysis and Trends*, p. 55, which was in turn prepared based on data collected in the 1992 IEA Computers in Education Study.

[123] In fairness, it should be noted that much remains to be learned about the actual educational outcomes associated with each category of activity, as discussed in Sections 4 and 8.

[124] To the extent that technology may have historically been deployed and used in a suboptimal fashion in the case of low-SES student populations, such problems may have arisen in part from certain rather restrictive rules that were once associated with the Title I program. Subsequent changes to the Title I program, however, may ultimately help to ameliorate these effects.

Among the factors that may be contributing to the disadvantages experienced by low-SES students in both the amount and nature of computer use are (putative) differences in the degree to which teachers in wealthy and impoverished schools have acquired the knowledge and skills necessary to use technology effectively in their teaching. While the Panel is aware of no research that explicitly compares the technology-related preparation of and ongoing support available to teachers in schools of different socioeconomic composition, anecdotal evidence suggests that significant differences may in fact prevail across socioeconomic lines.[125] Wealthy school districts may be able to recruit teachers with greater expertise in the use of educational technologies by offering above-average salaries, or to offer their existing teachers more technology-related training and technical support. Poorer schools, on the other hand, may have fewer teachers capable of making effective use of educational technologies, thus limiting both the quality and quantity of computer use by their students.

The most significant disparities in SES-related access to technology, however, are currently found not in the schools, but in the homes of their students. As of June 1995, computers were present in only 14 percent of all households headed by adults who had completed no more than a high-school education, and in which annual household income was less than $30,000; the comparable figure for households headed by college-educated adults having a combined income of more than $50,000 per year was more than five times greater, at 73 percent.[126] By contrast with the schools, however, there are presently no federal programs designed to facilitate the placement of computers within the homes of disadvantaged students.

As interactive information technologies come to be used increasingly for school work and other forms of learning, SES-linked differences in the ownership of home computer systems threatens not only to perpetuate existing familial patterns of socioeconomic disadvantage, but to widen the gap between the most and least affluent Americans. At a time when U.S. income inequality has reached its highest level since 1947 (when the Census Bureau began monitoring

[125] See, for example, Charles Pillar, "Separate Realities," *MacWorld*, September 1992, pp. 218-230.

[126] Times Mirror Center for the People and the Press, *Americans Going Online ... Explosive Growth, Uncertain Destinations* (Washington, D.C.: Times Mirror Center for the People and the Press, 1995), p. 12.

the relevant index),[127] the educational implications of SES-related disparities in home computer ownership should be regarded as a source of serious concern from a public policy viewpoint.

While it will be difficult to eliminate all SES-based inequities in the accessibility of educational technology within the context of current efforts to restrain federal spending, a number of possible federal actions are worthy of consideration. First, the Panel believes that the potential contributions of information technologies to elementary and secondary education are so substantial that minimum standards should be formulated and maintained for the use of technology within all of the nation's schools, regardless of the socioeconomic status of their student populations. Title I spending for technology-related investments on behalf of economically disadvantaged students (including hardware and software, telecommunications and networking services, professional development for teachers, and ongoing technical and pedagogical support) should be maintained at no less than its current level, with ongoing adjustments for inflation and for projected increases in both nationwide school enrollment and nationwide educational technology spending.

The Federal Communications Commission should fully exploit the powers granted to it under the Telecommunications Act of 1996 (discussed in Section 9.2), among others, to ensure that economically disadvantaged schools are provided with affordable telecommunications services and wide area network connectivity through preferential rates from telecommunications carriers, various forms of cross-subsidies, and/or the allocation of portions of the radio frequency spectrum for educational networking.[128] Consideration should also be given to the provision of various forms of private sector incentives for the expeditious wiring of impoverished rural and inner city schools to support local- and wide-area networking. Existing federal programs serving low-income stu-

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127 Daniel H. Weinberg, *Current Population Reports: A Brief Look at Postwar U.S. Income Inequality*, U.S. Census Bureau Document P60-191 (Washington, D.C., June 1996), p. 1. It is worth noting that the trend toward rising income inequality persists even after accounting for the effects of taxes, non-cash benefits, and government transfer payments, at least during the period between 1979 (when the Census Bureau began collecting the data necessary to compile the relevant statistics) and 1994 (Weinberg, *U.S. Income Inequality*, p. 3).

128 Special attention should be given to the provision of affordable Internet access to rural schools in which access to commercial online services and Internet service providers is either unavailable or unusually expensive.

dents should be reviewed with an eye toward exploiting the opportunities provided by computing and networking technologies, while public policy related to the ownership and disposition of various forms of intellectual property should be examined with the aim of providing affordable (and in many cases, free) access to a rich body of digital content (including digitized versions of certain material now owned or controlled by the federal government itself) that might not otherwise be accessible to less affluent schools.

The substantially lower prevalence of computers within the homes of low-SES students may be among the most difficult forms of inequity to remedy. At the same time, it may prove difficult to provide the sort of educational (and indirectly, economic and social) opportunity that our nation has striven to offer each American without addressing this disparity. The provision of modern computer systems and Internet connectivity in libraries, community centers, and other public institutions and spaces could represent an important first step in affording access to those students whose families are unable to provide such facilities at home, as would the provision of extended after-school and weekend access to technology within the schools themselves. Even if the amount of equipment available in such public locations were increased sufficiently to allow ongoing, regular use by a substantial number of students, however, the flexibility and convenience of home access would continue to confer a relative advantage on families able to afford to purchase computer equipment and online access.

Mindful of the significance of home access, several experimental pilot programs[129] have made it possible for students to borrow laptop computers from the school in much the same way as schools have traditionally loaned out musical instruments, thus providing full-time computer access to students both at school and at home. While the cost of such programs remains substantial within the limitations imposed by current technology, the results have been

[129] Examples include Project PULSE , at Abraham Clark Jr./Sr. High School in Roselle, NJ (Margaret Honey and Katie McMillan, *Project PULSE: Pupils Using Laptops in Science and English—Year One: A Final Report,* New York, Center for Children and Technology, Education Development Center, 1992) and Project TELL (Telecommunications for Learning), which is jointly administered by the Graduate School of the City University of New York, NYNEX, and the New York City Board of Education (*Project TELL II: College Incentive Program, Mid-Term Report, May 1994 to October 1995,* Graduate School and University Center, City University of New York, 1996).

quite promising, and it seems possible that new system architectures (perhaps based on the use of television sets as monitors) could decrease the associated costs to the point where universal home access might be contemplated as a realistic policy goal. There may also be opportunities to integrate the goal of universal home access within various existing federal programs—requiring, for example, the installation within all newly constructed federal housing projects of conduit or raceways capable of supporting future networking needs in a cost-effective manner.

## 7.3 Race and Ethnicity

While Title I funding has in recent years helped to significantly improve the density of computers in those schools attended by most minority students,[130] schools with more than a 90 percent minority enrollment still have 16 percent fewer computers per capita than other schools.[131] Computer density inequities associated with race and ethnic origin are partly accounted for by statistical differences in the socioeconomic variables discussed in the previous subsection, but certain disparities appear to be specifically attributable to race or ethnicity. Hispanic students, for example, appear to be singularly disadvantaged, attending schools with significantly fewer computers per student than average, particularly at the elementary school level.[132]

As in the case of socioeconomic status, racial and ethnic disparities in the accessibility of technology within the home constitute an even greater source of concern than within the school. In 1993, for example, African-Americans were 57 percent less likely to have a computer at home, and Hispanics 59 percent less likely, than non-Hispanic whites. Even after adjusting for household income,

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[130] By way of illustrative baseline comparison, in 1985 an African-American elementary school student was about *three times* as likely as a white elementary school student to attend a school that had no computers. See Henry J. Becker and Carleton W. Sterling, "Equity in School Computer Use: National Data and Neglected Considerations," *Journal of Educational Computing Research* 3 (1987), p. 296.

[131] Derived from QED, *Technology in Public Schools*, 14th Edition, p. 32, and from data provided by Laura Zawacki, QED (private telephone communication, 1996).

[132] Survey-based estimates of the magnitude of this disadvantage have ranged from a 13 percent lower computer density than that experienced by the average non-Hispanic white student (based on the 1993 QED data) to a 19 percent (and at the elementary school level, 23 percent) lower density than that of the average student of any race (based on the 1992 IEA data), in each case as analyzed by Becker *(Analysis and Trends*, p. 51).

educational attainment, age, gender, and location of residence (urban or rural), home computer ownership was 36 percent and 39 percent less common among African-Americans and Hispanics, respectively, than among non-Hispanic whites.[133] This gap in ownership is reflected in the usage of home computers by children: In a 1995 survey, for example, children were found to use computers within 38 percent of all white households, but only 17 percent of all black homes.[134] Even ordinary telephone service, which will be important for the support of home/school communications and for access to the many resources available over the Internet, is not available equally to all racial or ethnic groups, with Native Americans, Hispanics, and African Americans in particular reporting less access than average, especially in rural areas.[135]

Because a large part of the racial and ethnic imbalance in access to educational technology is attributable to socioeconomic factors, interventions of the sorts discussed in Section 7.2 should help to equalize the opportunities available to students of different races and ethnic origin as well. Since race and ethnicity are also associated with access inequalities that are not fully explained by socioeconomic status, however, government policy should be informed as well by an independent concern for racial and ethnic fairness. Equitable access to information technologies should be among the explicit objectives of programs for the education of bilingual and migrant students, for the setting of educational standards, for the reform of assessment protocols, and for the accreditation of teachers and of education schools. Racial, ethnic, and cultural diversity should also be taken into consideration when designing educational software and when prioritizing the digitization of educational content, supported by federally supported ethnographic research and by higher educational and apprenticeship programs designed to enhance diversity within the professional community that develops such programs and content.

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[133] Derived from figures presented in Table A.3 of Robert H. Anderson, et al., *Universal Access to E-Mail: Feasibility and Societal Implications* (Santa Monica, CA: RAND Corporation, 1995), p. 184, which was in turn based on U.S. census data extracted from *Current Population Survey, October 1993* (machine-readable data file) (Washington, D.C.: Bureau of the Census, 1994).

[134] Margaret Petrella, Pew Research Center for the People and the Press, Washington, D.C., private telephone communication, August 1996, based on unpublished data from a 1995 survey whose principal results appear in Times Mirror Center, *Technology in the American Household*, 1995.

[135] U.S. Department of Commerce, *Falling Through the Net: A Survey of the "Have Nots" in Rural and Urban America* (Washington, D.C., July 1995), pp. 3-4, Table 4.

## 7.4 Geographical Factors

When the United States is divided into four regions—West, Midwest, Northeast, and South—for comparative purposes, students in these regions are found to encounter an in-school computer density that differs by no more than ten percent from the national average.[136] Certain regional differences do exist, however, in the *use* of technology. Students in the Southern region, for example, are 32 percent less likely to be *heavy* users of school computers,[137] and 25 percent less likely to use computers for "higher-order or mixed" activities,[138] than Western students. Examining the density and use of computers along a different dimension, students in rural schools have (somewhat surprisingly) been found to enjoy a 24 percent higher ratio of computers to students than those attending suburban schools, and fully 40 percent higher than students enrolled in city schools.[139] These effects largely vanish, however, when school size is statistically controlled;[140] it would appear that rural schools may have more computers per student only because they are smaller.[141]

Certain forms of access inequities are not evident when schools are coarsely categorized by region and urbanicity, but become apparent when other, finer-grained classificatory schemes are used to identify geographical groupings characterized by common (actual or potential) problems. Inner city students, for example, are clearly immersed in an environment that differs markedly from that of a wealthy urban neighborhood or a middle-class "edge city," and are likely to suffer special disadvantages, and to have special needs, that do not

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[136] IEA Computers in Education Study, as analyzed and reported in Table 6.2 of Becker, *Analysis and Trends*, p. 51.

[137] Derived from figures reported in Table 6.5 of Becker, *Analysis and Trends*, p. 55, which are in turn based on data provided by students in the 1992 IEA Computers in Education Study. "Heavy" use was defined according to an activity index based on the frequency with which each surveyed student reported engaging in each of nine distinct computer-based activities.

[138] Derived from Table 6.6A of Becker, *Analysis and Trends*, p. 55, which is again based on student data from the 1992 IEA Computers in Education Study.

[139] These (enrollment-weighted) computer density figures were derived from Table 6.2A of Becker, *Analysis and Trends*, p. 51, which is based on the 1992 IEA Computers in Education Study.

[140] Based on a multivariate regression analysis of the 1992 IEA survey data reported in Becker, *Analysis and Trends*, p. 52.

[141] See Footnote 109 for a brief discussion of the relationship between computer density and school size.

surface in surveys that treat all three as members of the single category "urban."[142] Such studies may also miss the problems faced by certain rural schools located in areas lacking the local "points of presence" or affordable high-bandwidth telecommunication links that are typically required to provide cost-effective access to online services and Internet service providers. Schools located within geographic areas in which there is little technology-oriented business activity may also be disadvantaged relative to those in high-tech areas.[143] While individual states and school districts may well be in the best position to solve some of these problems, the Panel believes that the federal government has an important role to play in monitoring the use of educational technology throughout the country with an eye toward minimizing the extent to which the educational opportunities available to our children are constrained by geographical happenstance.

## 7.5 Gender

On average, girls and boys differ only slightly in their use of computers at school. The 1992 IEA data set yields results that are typical of studies in this area, indicating that boys make three percent greater use of school computers than girls.[144] Another survey, however, suggests that boys and girls differ significantly in the *ways* in which they use computers at school. Although high school girls made 50 percent greater use of the computer for word processing than their male classmates, for example, they accounted for only 26 percent of all elective computer use before and after school, and for only 20 percent of all in-school computer-based game-playing activities.[145]

As in the school, overall gender differences in computer use within the home are small. In a 1994 survey, for example, 53 percent of all parents reporting use

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142 Additional research based on contemporary demographic clustering techniques might well help to tease out the nature and magnitude of such finer-grained geographical effects.

143 The effect of such differences on the differential availability of volunteers capable of providing technology-related assistance to the schools is discussed briefly in Section 9.3. In addition, schools in certain geographic areas may be handicapped by a relative lack of commercially available technical support and consulting services.

144 Derived from data reported in Table 6.4A of Becker, *Analysis and Trends*, p. 54.

145 Derived from figures presented in Table 6, Becker and Sterling, "Equity in School Computer Use," p. 302.

of a home computer by one or more children indicated that the most frequent user was a boy, while 47 percent said that a girl made heaviest use of the computer. Again, however, the *nature* of that use differed: Girls were more likely to use a home computer for school work and for word processing,[146] while boys were nearly twice as likely to play (non-educational) computer-based games.[147]

A modest amount of research has attempted to identify factors that might account for gender-specific differences in the appeal and effectiveness of certain types of programs and of various environments and contexts for computer use.[148] The differential use of word processing software may well be related to other gender-specific differences in linguistic behavior, and gender-related social factors (aggressive contention for computer resources by boys in certain school environments, for example, which may intimidate their female classmates) may account for the lesser participation of girls in certain forms of unstructured, elective computer-based activities.[149] There is also some evidence that girls and boys engaging in computer-related learning activities may differ in their relative responses to cooperative, competitive, or individualistic reward structures.[150]

Much remains to be learned, however, about the technology-related proclivities and usage patterns of male and female students of various ages. Although neither boys nor girls would appear to suffer a clear disadvantage in the *overall* use of computers, the differential usage patterns observed both at school and

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[146] Forty-six percent of all girls and 35 percent of all boys were reported to use a computer at home for school work. The corresponding figures for word processing were 42 percent and 31 percent, respectively. Questions were posed, however, in such a way that these two categories were not considered mutually exclusive, suggesting the possibility that the former difference is in fact accounted for in large part by the latter. (Times Mirror Center, *Technology in the American Household*, p. 31.)

[147] Forty-seven percent of all boys played non-educational games, compared with only 24 percent of all girls. Boys and girls, however, did not differ significantly in their use of the computer to play *educational* computer games. (Times Mirror Center, *Technology in the American Household*, p. 31.)

[148] For a brief review of some of this work, see Rosemary E. Sutton, "Equity and Computers in the Schools: A Decade of Research," *Review of Educational Research* 61 (1991), pp. 484-485.

[149] Sutton, "Equity and Computers," pp. 485-486.

[150] Roger T. Johnson, David W. Johnson, and Mary Beth Stanne, "Effects of cooperative, competitive, and individualistic goal structures on computer-assisted instruction," *Journal of Educational Psychology* 77 (1985), pp. 668-677.

within the home raise the question of whether further research might lead to software, content, and user environments that more effectively serve the needs of both.

## 7.6 Educational Achievement

Available evidence suggests that educational technologies may be even more valuable to low-achieving students than to their higher-achieving peers.[151] While a meta-analysis that examined (among other things) 20 studies of the instructional use of word processing found a 27 percent average improvement in writing quality overall, for example, the nine studies that were based on programs for remedial students showed an average improvement of 49 percent.[152] Educationally disadvantaged students in another computer-based instruction program recorded a 90 percent average performance improvement in mathematics—far higher than the gains typically realized by high-achieving students.[153] In spite of the potential value of educational technology for low-achieving students, however, such students would appear to have *less* in-school access to computers than higher achievers, particularly at the high school level. In the 1992 IEA Computers in Education survey, for example, 11th grade students whose grades fell in the bottom 32 percent of the sample reported using school computers for an average of 22 percent fewer hours than the 19 percent whose grades were highest.[154]

Another way in which underperforming students may be disadvantaged with respect to their higher-achieving classmates is in the different types of computer-based learning activities to which they are exposed. While high achievers may be allowed to use computers in the performance of relatively complex,

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151 It should be acknowledged, however, that such statements are somewhat ill-defined under circumstances in which there is no straightforward way to compare performance improvements measured within different regions of the performance scale.

152 Robert L. Bangert-Drowns, "The word processor as an instructional tool: A meta-analysis of word processing in writing instruction," *Review of Educational Research* 63 (1993), pp. 69-93.

153 Karen Swan, Frank Guerrero, Marco Mitrani, and John Schoener, "Honing in on the target: Who among the educationally disadvantaged benefits most from what CBI?" *Journal of Research on Computing in Education* 22 (1990), pp. 381-403.

154 Derived from data reported in Tables 6.4A and 6.4B of Becker, *Analysis and Trends*, p. 54.

"authentic" tasks involving the acquisition and integration of a wide range of factual and procedural knowledge, low-achieving students are more likely to be assigned extensive drill and practice on isolated basic skills—presumably on the assumption that remediation in these areas is a prerequisite to activities requiring higher-level thinking and problem-solving skills. Many researchers now feel, however, that such sequencing, however intuitively plausible, is in fact ill-conceived, and should be abandoned in favor of a unified approach in which both high- and low-achieving students acquire basic skills in the course of undertaking substantial, "real world" tasks of the sorts discussed in Section 4.3.

## 7.7 *Students with Special Needs*

Technology may present special challenges to students with learning disabilities, behavioral disorders, emotional problems, or physical disabilities, but may also provide them with unique opportunities for more effective learning. In the case of such students, *equal* access may not imply *equitable* access; special measures must sometimes be taken to ensure that they are afforded the maximum possible benefit from the use of educational technology. Fortunately, technology itself may often prove instrumental in providing such special assistance.[155]

Children with certain mobility or sensory impairments, for example, may be able to use single-finger devices, joysticks, mouthsticks, or other specialized hardware to provide input to the computer. Students unable to enter data on a conventional keyboard may be able to achieve the same effect through the use of "eye gaze" technology, or by using a "single switch" device together with special keyboard scanning software to select first a row, then a column, from a "virtual keyboard" depicted on the monitor. Those who are unable to use a mouse may be able to employ an alternative device together with a specialized screen display to emulate conventional point-and-click operations. Shorthand (based on either the standard Gregg system or the expansion of user-defined

[155] While educationally significant "assistive technologies"—systems and devices designed to increase the independence of a disabled person—constitute the principal focus of this discussion, it should be noted that some have argued for a greater emphasis on the application of "universal design" principles (involving, for example, the incorporation of redundant input and output mechanisms) to ensure that technology is usable by persons with a wide range of disabilities as well as by the general population.

abbreviations) or interactive word prediction software may be used to reduce the number of keystrokes required for keyboard input. Alternatively, Morse code interpretation software can be used to support the input of arbitrary characters using a single-switch device, or speech recognition algorithms may be used to provide voice recognition capabilities within certain educational applications.

Assistive output technologies for students with disabilities include magnification programs for low-vision students and systems that use voice synthesis technology to read out screen information or the contents of printed documents to blind students. The latter technology may also be incorporated in "augmentative communication systems" that allow non-speaking students to converse using digitally synthesized speech. Both local- and wide-area networks may be used to permit students with various forms of mobility limitations or communication impairments to access and exchange information, making available valuable learning resources that might otherwise be inaccessible. Technology also has the potential to significantly expand the educational opportunities available to children with learning disabilities—currently the largest category of students with special needs—and may prove valuable for children with emotional problems or behavioral disorders as well, though further research will be necessary to characterize the ways in which technology might best be deployed on behalf of such students.

The essential role of the federal government in insuring access to educational technologies for students with special needs arises in part from the fact that, within a typical school district, the number of students with a given disability is likely to be too small to adequately amortize the cost of researching, developing, and effectively deploying the assistive technologies that would provide appropriate educational support for those students. In the case of less common disabilities, even the typical state is unlikely to have the resources that would be necessary to independently provide the necessary support. Federal funding should thus be provided for research on the use of technology to support learning by students with various forms of disabilities, for the development of assistive hardware and software for use in the school, and for professional training in the use of such technologies.

# 8. Research and Evaluation

In view of both the significant changes and the substantial investment in hardware and infrastructure, software and content, professional development, and support services that will be required to make effective use of computing and networking technologies within our nation's K-12 schools, it is perhaps not surprising that researchers, educators, policy-makers, and taxpayers have inquired as to the available evidence regarding the efficacy and cost-effectiveness of educational technology. In addition (and in the judgment of the Panel, more importantly), any research that sheds light on how technology might be employed in a *more* efficacious (according to some reasonable set of criteria) or cost-effective manner would be of great value in maximizing the ratio of benefit to cost. With our nation now spending more than a quarter trillion dollars each year on K-12 education, even small improvements in this ratio could have a material impact on America's aggregate state and federal budget deficit (as affected by the denominator) and future economic competitiveness (as influenced by the numerator).

We begin this section with a brief overview of what is currently known—and equally important, what remains to be learned—about the effectiveness of various traditional and constructivist approaches to the use of educational technologies. This is followed by a discussion of certain issues related to the measurement of educational outcomes, and to the implications of these issues for the comparison of alternative approaches to the use of technology. Questions related to the funding and administration of educational technology research are considered in the following subsection, and are followed by the Panel's general assessment of current research priorities. The final subsection examines the case for federally sponsored research in educational technology from both a theoretical and a practical viewpoint, and concludes with what is probably the most significant recommendation of this report: that the federal government dramatically increase its investment in research aimed at discovering what actually works, not only with respect to the application of educational technology, but in the field of elementary and secondary education in general.

## 8.1 *Effectiveness of Traditional Applications of Technology*

A substantial number of studies have been conducted over the past several decades with the aim of assessing the effectiveness of traditional, tutorial-based CAI applications of the sort discussed in Section 4.1. While the experiments reported in the literature were performed on various student populations, using various instructional approaches, within various natural and laboratory environments, and employing various experimental paradigms, a number of researchers have used meta-analytic techniques[156] to aggregate the results of these studies in an attempt to arrive at a quantitative assessment of the utility of computer systems within the field of education.

The findings of four such meta-analyses, each based on data gathered from dozens of separate studies on the effects of "traditional" computer-based instruction[157] at the K-12 level, are summarized in Table 8.1. Each of these four meta-analyses found that students using computer-based systems outperformed those taught without the use of such systems, with the magnitude of the average outperformance computed in each meta-analysis varying between 25 and 41 percent of a standard deviation. The benefits of such traditional appli-

[156] In a meta-analysis (Gene V. Glass, Barry McGaw, and Mary Lee Smith, *Meta-Analysis in Social Research* (Beverly Hills, CA: Sage Publications, 1981)), the outcomes of a number of studies, selected according to well explicated, predefined criteria, are converted into a common, normalized form (in the cases considered here, the "Glass effect size," computed as the difference between the outcomes measured in the experimental and control groups, expressed in number of standard deviations) so that conventional multivariate statistical methods can be used to obtain an aggregated quantitative measure of the effect of interest. Among the attractive properties of such techniques is the ability to derive greater statistical power in the aggregate than is present in any one of the constituent studies; even in the case where *none* of the individual studies supports rejection of the null hypothesis according to conventional standards of statistical significance (due to small sample size, for example, or to a low "signal-to-noise ratio"), the results of a meta-analysis based on those studies may in some cases be highly significant. It should be noted, however, that some researchers have questioned the applicability and utility of meta-analytic techniques in the context of educational outcome measurement, and that some prefer to rely on traditional (non-quantitative) narrative reviews, while others have proposed alternative techniques (see, for example, Robert E. Slavin, "Best-Evidence Synthesis: An Alternative to Meta-Analytic and Traditional Reviews," in *Evaluation Studies Review Yearbook, Vol. 12*, ed. William R. Shadish and Charles S. Reichart (London: Sage Publications, 1988)) for the quantitative abstraction of results gathered from multiple studies.

[157] We have included in this category applications described as either "drill and tutorial," "computer-assisted instruction," "computer-enriched instruction" or "computer-managed instruction" in James A. Kulik, "Meta-Analytic Studies of Findings on Computer-Based Instruction," in *Technology Assessment in Education and Training*, ed. Eva L. Baker and Howard F. O'Neil, Jr. (Hillsdale, NJ: Lawrence Erlbaum, 1994), Table 1.1, p. 12, from which this data was obtained.

cations have generally been found strongest in the case of students of lower socioeconomic status, low-achievers, and those with certain special learning problems.[158] In addition, students using such systems have generally been found to learn significantly faster, to enjoy their classes more, and to develop more positive attitudes toward computers (although not necessarily toward the subject matter being taught).[159]

*Table 8.1*

**Meta-Analyses of the Effectiveness of Traditional Computer-Based Instruction**[160]

| *Meta-Analysis* | *Number of Studies* | *Instructional Levels* | *Average Effect Size*[161] |
|---|---|---|---|
| Hartley (1978)[162] | 33 | Elementary & secondary | 0.41 |
| Burns & Bozeman (1981)[163] | 44 | Elementary & secondary | 0.36 |
| Bangert-Drowns, Kulik & Kulik (1985)[164] | 51 | Secondary | 0.25 |
| Kulik, Kulik & Bangert-Drowns (1990)[165] | 44 | Elementary | 0.40 |

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[158] Barbara Means and Kerry Olson, "Technology's Role in Educational Reform," report for the U.S. Department of Education, Office of Educational Research and Improvement (Washington, D.C.: September 1995.

[159] Kulik, "Meta-Analytic Studies."

While the preponderance of evidence would seem to argue for the efficacy of traditional computer-assisted instruction, some researchers have raised questions related to the methodology employed in these studies, or to the interpretation or import of the results they yielded. In particular, issues have been raised regarding the size and experimental designs of many of the underlying studies, the amenability of these studies (which often differ significantly in multiple dimensions) to meta-analytic aggregation, the robustness (after controlling for various contextual factors) and temporal persistence of the measured effects, the independence of those responsible for evaluating efficacy, and the possibility of systematic bias against the publication of negative results.[166]

Given adequate funding, all of the above questions could be addressed through a well-designed program of rigorous, carefully controlled, independently replicated research conducted over a reasonable period of time. Such a program, however, would still not address what may well be the most important issue associated with the evaluation of traditional applications of educational technology using traditional measures of educational achievement: whether the variables being measured are in fact well correlated with the forms of learning we wish to facilitate.

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160 Adapted from Kulik, "Meta-Analytic Studies," Table 1.1, p. 12.

161 Mean Glass effect size, as defined in Footnote 156.

162 S. S. Hartley, "Meta-Analysis of the Effects of Individually Paced Instruction in Mathematics," *Dissertation Abstracts International, 38(7-A)*, 4003 (University Microfilms No. 77-29, 926, 1978).

163 P. K. Burns and W. C. Bozeman, "Computer-assisted instruction and mathematics achievement: Is there a relationship?" *Educational Technology* 21 (1981), pp. 32-39.

164 Robert L. Bangert-Drowns, James A. Kulik, and Chen-Lin Kulik, "Effectiveness of Computer-Based Instruction in Secondary Schools," *Journal of Computer-Based Instruction* 12 (1985), pp. 59-68, as updated in Chen-Lin Kulik and James A. Kulik, "Effectiveness of computer-based instruction: An updated analysis," *Computers in Human Behavior* 7 (1991), pp. 75-94.

165 Chen-Lin Kulik, James A. Kulik and Robert L. Bangert-Drowns, "Effectiveness of Mastery Learning Programs: A Meta-Analysis, *Review of Educational Research* 60 (1990), pp. 265-299, as updated in Kulik and Kulik, "Effectiveness of computer-based instruction," pp. 75-94.

166 It should also be noted that much of the research summarized here was based on text-only applications executed on early, time-shared minicomputer systems. Generalizations to a contemporary computational environment based on networked personal computers with extensive graphics capabilities must thus be approached with caution.

## 8.2 Research on Constructivist Applications of Technology

In view of the emphasis placed by current educational reform efforts on higher-order thinking and problem-solving activities and on learning models based on the active construction by each student of his or her own knowledge and skills, it is natural to ask what is currently known—and what remains to be learned—about the extent to which widely usable constructivist applications of computing and networking technologies (as discussion in Section 4.3) in fact achieve desirable educational outcomes in a cost-effective manner. A review of the relevant research literature, however, suggests that although a substantial amount of very interesting and potentially significant work has already been done, we are not yet able to answer this question (nor, indeed, even to define it precisely) with the degree of certainty that would be desirable from a public policy viewpoint.

Although a limited number of (often quite promising) empirical studies have already been published, much of the research literature dealing with constructivist applications of technology consists of theoretical and critical analysis, reports of informal observations, and well-articulated but high-inference reasoning based on research conducted over the past two decades in cognitive, developmental and social psychology, and in such areas as artificial intelligence, adolescent motivation, and even international economics and human resource management. Although this progenitive research is itself often quite sound, the specific pedagogical applications to which such theory has given rise in the field of educational technology have thus far been subjected to only limited (though by no means negligible) rigorous experimental testing.

Research in the interdisciplinary field of cognitive science, for example, has in recent years provided convincing evidence that the human processing of visual, linguistic and other data entails the active fitting of such input into a rich internal framework of "real world" knowledge and expectations, and not simply the passive assembly of a mass of external data into an emergent whole. Our understanding of human learning has similarly evolved (based on a wealth of evidence collected over a wide range of different domains and media) from a process based on the passive assimilation of isolated facts to one in which the learner actively formulates and tests hypotheses about the world, adapting, elaborating, and refining internal models that are often highly procedural in nature.[167]

There is little question that such research provides fertile ground for the formulation of compelling *hypotheses* regarding the ways in which traditional pedagogical methods might be modified to take advantage of these advances in our understanding of the nature of perception, cognition, and learning. It is well to remember, however, that the history of science (and more specifically, of educational research and practice) is replete with examples of compelling application-specific hypotheses that seem to arise "naturally" from well-founded theory, but which are ultimately refuted by either rigorous empirical testing or manifest practical failure.[168] Knowledge of the nature of learning and thought is closely related to, but nonetheless distinct from, knowledge of the best ways to cause such learning to take place. While the former may well prove to be of immeasurable assistance in the course of acquiring the latter, it is important that a confounding of the two not lead us to underestimate the importance of empirical research aimed at *validating* our hypotheses concerning the efficacy and cost-effectiveness of specific constructivist applications of technology.

These observations are by no means intended as a *criticism* of educational technology research based on constructivist principles; rather, they reflect the fact that such research is still at a relatively early stage of development. Much of the research currently being conducted on constructivist applications of technology is *formative* in nature—intended more as a preliminary exploration of new intellectual territory than a definitive evaluation of any one possible solution. Such research is often (and in the case of many constructivist applications, necessarily) characterized by the simultaneous manipulation of a number of different variables, and should ultimately be followed by subsequent (and

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[167] The distinction we are drawing here is between *declarative* knowledge (for example, the fact that the square of a negative real number is always positive) and *procedural* knowledge (an algorithm for alphabetizing a list of words, for example, or a strategy for attacking a complex problem by first solving a related, but simpler problem).

[168] Indeed, the widespread current acceptance of the central tenets of constructivism within the educational reform movement, combined with the fact that constructivist practice *seems* to follow so naturally from a well-established body of underlying scientific theory, should perhaps lead us to be especially vigilant in guarding against an ideological (rather than a scientific) approach to the evaluation of educational applications of technology.

often time-consuming) experiments designed to tease out the underlying sources of any positive effects. Formative research on constructivist applications of technology also tends to be more difficult to generalize to other educational contexts than is the case for traditional computer-assisted instruction. Additional research may be required, for example, to determine the extent to which positive effects persist in the hands of less capable or less motivated teachers, within different sorts of student populations, or in the absence of comparable financial resources.

In fairness, it should be noted that some useful empirical work has already been done to validate the efficacy of educational approaches based in various ways on a constructivist pedagogical model. Moreover, such results as have been reported thus far have generally been both interesting and encouraging. One example is provided by *The Adventures of Jasper Woodbury*, a series of extended, open-ended, videodisc-based problem-solving exercises developed by the Cognition and Technology Group at Vanderbilt University. While students participating in the Jasper program acquired basic mathematical concepts at about the same rate as matched controls,[169] superior performance was measured on relatively complex single- and multistep word problems, and on various high-level planning tasks requiring the formulation of multiple subgoals.[170] Other researchers have published promising empirical results related to the use of software tools,[171] network-based collaboration,[172] and computer simulation[173] within a constructivist framework.

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169 Given the fact that students involved in the Jasper program had less time available for basic math instruction, the attainment of parity in this dimension is itself worthy of note.

170 Cognition and Technology Group at Vanderbilt University, "The Jasper Series as an Example of Anchored Instruction: Theory, Program Description, and Assessment Data," *Educational Psychologist* 27 (1992), pp. 291-315.

171 See, for example, C. M. Gardner, P. E. Simmons, and R. D. Simpson, "The Effects of CAI and Hands-On Activities on Elementary Students' Attitudes and Weather Knowledge," *School Science and Mathematics* 92 (1992), pp. 334-336; and Bangert-Drowns, "The Word Processor as an Instructional Tool," pp. 69-93.

172 See, for example, Margaret Riel, "Cooperative Learning Across Classrooms in Electronic Learning Circles," *Instructional Science* 19 (1990), pp. 445-466.

173 Although gathered within a different context (the training of U.S. military personnel), a substantial body of empirical data related to the effectiveness of computer simulation-based learning is summarized in Jesse Orlansky, Carl J. Dahlman, Colin P. Hammon, John Metzko, Henry L. Taylor, and Christine Youngblut, "The Value of Simulation for Training," IDA Paper P-2982 (Alexandria, VA: The Institute for Defense Analysis, September 1994).

Overall, however, considerably less empirical research has been done on the effectiveness of constructivist applications of technology than on traditional, tutorial-based applications. This disparity is attributable to several factors. The first arises from the relative lack of well-defined, well-accepted metrics for the comparative evaluation of educational outcomes within a constructivist context. Conventional, standardized multiple-choice tests offer the advantages of widespread availability, straightforward administration and scoring, and familiarity to and credibility with the public at large. Such tests, however, tend to place greater emphasis on the accumulation of isolated facts and basic skills, and less on the acquisition of higher-order thinking and problem-solving skills, than would be desirable for the measurement of those forms of educational attainment that are central to current educational reform efforts.

If the goals of the educational reform movement are to be reached, it is essential that care be taken to establish what Hawkins refers to as "a system in which the pedagogy is not in tacit conflict with the accounting."[174] Since researchers, educators and software developers can be expected to develop content and techniques that optimize student performance with respect to whatever criteria are employed to measure educational attainment, progress will depend critically on the development of metrics capable of serving as appropriate and reliable proxies for desired educational outcomes, and enjoying reasonably widespread acceptance by researchers, educators, parents, and legislators.[175]

While empirical research on constructivist applications of technology has been complicated by questions related to the manner in which "favorable" educational outcomes should be defined and measured for purposes of evaluating the relative effectiveness of alternative approaches, progress has also been impeded by a critical lack of funding, as discussed in Section 8.4. Even in the ab-

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[174] Jan Hawkins, "Dilemmas," in *Education and Technology: Reflections on Computing in Classrooms*, ed. Charles Fisher, David C. Dwyer, and Keith Yocam (San Francisco, CA: Jossey-Bass, 1996).

[175] The importance of community support for the metrics that will be used to evaluate educational outcomes is illustrated by the case of Belridge School, in McKittrick, CA, which invested heavily in the acquisition of technology for use in a constructivist-oriented K-8 program aimed primarily at the development of higher-order thinking skills through involvement in various challenging, "authentic" tasks. Although the program was not designed with the goal of increasing standardized test scores, parents were angered when average scores on the Iowa Test of Basic Skills failed to increase after the program's first year, and picketed the school, demanding that the program be terminated in favor of a "back to basics" agenda.

sence of such factors, the development of a rich evaluative literature is an intrinsically time-consuming process. It would be unrealistic to expect the literature to be as broad and mature in the case of educational technology based on constructivist principles as the body of primary research and meta-analysis that has been developed over a period of several decades for traditional computer-based tutorial applications. Although time and resources will be required to develop a firm, scientific understanding of the strengths and limitations of the constructivist approach and (perhaps more importantly) of the specific techniques that are likely to prove most effective and cost-effective in practice, the Panel believes such research to be critically important and worthy of substantial and sustained federal support.

## 8.3 *Priorities for Future Research*

While research in a wide range of areas could directly or indirectly facilitate the effective utilization of educational technology within our nation's K-12 schools,[176] much of the research that the Panel believes to be most important falls into one of the following three categories:

1. Basic research in various learning-related disciplines and fundamental work on various educationally relevant technologies

2. Early-stage research aimed at developing new forms of educational software, content, and technology-enabled pedagogy

3. Empirical studies designed to determine which approaches to the use of technology are in fact most effective

Among the underlying research areas encompassed by the first category are various aspects of cognitive and developmental psychology, neuroscience, artificial intelligence, and the interdisciplinary field of cognitive science, which have already shed substantial light on the nature of learning, reasoning, mem-

[176] Examples not discussed in this subsection include further studies of the ways in which computers are currently used in American schools; research on techniques (including those based on the *use* of technology) for preparing teachers to employ technology effectively within the classroom; investigations of various topics falling within the field of educational economics; and a number of aspects of educational research that, while not specifically dealing with the use of computers or networks, are nonetheless relevant to the ways in which technology might be most effectively utilized within the curriculum.

ory, and perception. In addition, several areas of research within the field of computer science have the potential to play important roles in the development of enabling technologies for educational applications. The potential value of continued progress on both the scientific and engineering fronts argues for the continued federal funding of both categories of research, which could ultimately provide significant returns not only in the area of educational technology, but in other areas of significance from a public policy viewpoint as well.

The second category of research that the Panel believes should be supported at the federal level includes exploratory work focusing on the development and preliminary testing of innovative new approaches to the application of technology in education which are unlikely to originate from within the private sector. While the *later* stages of research, development, and product engineering are likely to be driven largely by industrial efforts, there are both theoretical and empirical reasons to believe that only the federal government can be expected to provide an appropriate level of funding for much of the early-stage research that the Panel believes should now be conducted in the field of educational technology.

This situation arises from a particular form of economic externality related to the lack of appropriability of certain forms of intellectual property. Suppose, for example, that a particular private company (referred to below as Company A) were to expend significant resources on research aimed at the discovery of powerful new techniques for the application of technology to education. While Company A might well find it possible to commercially exploit any successful results that might be discovered in the course of its research—through the sale of a proprietary software product to schools, for example—it would generally be unable to prevent other companies from analyzing this product and using the benefits of this analysis to design a competing product, thus appropriating for themselves a portion of the returns accruing from the results of Company A's research, and consequently reducing Company A's profitability.

Anticipating its inability to capture the full benefit of its investment in research, Company A (and all of its competitors, since each would be faced with the same dilemma) may be expected to systematically invest less (and in many realistic cases, dramatically less) on research and development than would be optimal both from the economic viewpoint of Company A and its competitors in the aggregate, and from the viewpoint of students, schools, and society as a whole. Such "free-rider" problems are classically resolved through the use of pooled funding at the highest possible level of taxing authority—in this case, through investment at the federal level. (State or local funding would result in another free-rider problem, with each state or locality having an incentive to systematically underinvest in research funding in order to "ride in the tailwind" of the others.)

In the Panel's view, such economic externalities, combined with the potential "multiplier effect" that can be realized when carefully targeted early-stage government research funds are used to seed later-stage private sector R&D, provide a strong case for the federal funding of early-stage research aimed at developing new forms of educational software, content, and technology-enabled pedagogy. To date, the level of federal support for such research has been quite low relative to the associated potential returns, and such funding as has been available has been concentrated largely in the areas of mathematics and science education (where grants from the National Science Foundation have made a significant impact). While math and science will indeed play a critical role in preparing our children for the demands of the twenty-first century, the Panel believes that the level of federal funding for early-stage research on innovative applications of educational technology should be increased in *many* areas, including the language arts, social studies, and creative arts.

In order to maximize the likelihood of discovering intellectually divergent, but highly effective approaches, support should initially be provided for a substantial number of independent, investigator-initiated, early-stage research projects based on a wide range of alternative approaches. Research in this second category, however, will be preliminary and formative in character, and cannot be expected to yield definitive, reliable, broadly generalizable results that provide a clear indication as to which approaches to the use of educational technology are in fact likely to prove most effective in practice. The derivation of such empirical results is among the principal goals of the research described in the last of the three categories identified above.

In the Panel's judgment, the principal goal of such empirical work should *not* be to answer the question of whether computers can be effectively used within the school. The probability that elementary and secondary education will prove to be the one information-based industry in which computer technology does not have a natural role would at this point appear to be so low as to render unconscionably wasteful any research that might be designed to answer this question alone.

Even if it *were* deemed to be desirable to gather evidence for the overall effectiveness of technology in education, current educational trends would make the interpretation of such research more difficult than was the case in the early days of computer-assisted instruction. Technology has in recent years been increasingly seen not as an isolated addition to the conventional K-12 curriculum, but as one of a number of tools that might be used to support a process of comprehensive curricular (and in some cases, systemic) reform. In such an environment, attempts to isolate the effects of technology as a distinct independent variable may be both difficult and unproductive. The Panel believes the kinds of findings that might actually prove useful in practice are more likely to arise from research aimed at assessing the effectiveness and cost-effectiveness of specific educational approaches and techniques that make *use* of technology.

In view of the enormous investment our country makes in education each year and the high stakes associated with the quality of the education our children receive, it is essential that such research be conducted in a manner and on a scale that are capable of providing educators, policy-makers, parents, and the general public with well-grounded, scientifically credible results that can be applied with confidence in the context of actual educational decision-making. Early-stage, exploratory research of the sort described in the second category outlined above should be used to formulate well-explicated, falsifiable hypotheses suitable for rigorous empirical testing. These hypotheses should then be subjected to potential refutation through the execution of well-designed, carefully controlled experiments having sufficient statistical power to distinguish genuine effects of relatively modest size from differences that can easily be explained as chance occurrences.

One of the most obviously salient dimensions in the design of such experiments is size: once formative research has yielded hypotheses that are deemed sufficiently promising to warrant further evaluation, a number of independently conducted, large-scale empirical studies, each following a substantial number of students over a significant period of time, will be necessary to obtain statistically significant results involving a non-trivial number of dependent and independent variables. Since different approaches may prove optimal in different subject areas, at different grade and ability levels, with different sorts of teachers, and for students with different needs, interests, backgrounds, current knowledge, and learning styles, the systematic investigation of how technology might best be used to improve K-12 education in the United States is likely to involve hundreds of thousands of student-years of experimental research.

Another important consideration is the extent to which the results of a given empirical study can be generalized to other educational settings. While experimentation within an unusually enriched laboratory environment may well be productive under certain circumstances, it is important that a substantial amount of research also be conducted under conditions more typical of actual classrooms, using ordinary teachers (and not, for example, only those who are unusually well educated or highly motivated), and without access to unusual financial or other resources, for example, or to special outside support from university researchers. If our goal is to understand how technology can best be used within real schools, it is essential that, at some point, large-scale experiments actually be conducted within such schools.

Finally, it is important that the results of such research—whether positive or negative—be widely disseminated within the education and educational research communities. High standards of peer review should be encouraged within the scholarly journals that publish papers dealing with educational technology, and federal support should be provided for conferences and workshops designed to bring researchers together for regular, informal interaction as well as the timely presentation of new research results. Substantial federal funding should also be provided for high-quality doctoral research on the use of technology in education; apart from the direct contribution that such research can make to the state of knowledge within the field, federal support should help to increase the output of Ph.D.s capable of conducting further research in this area and/or preparing teachers to use technology effectively within their classrooms.

## *8.4 Research Funding*

In the long run, the Panel believes that much of the promise of educational technology is likely to remain unfulfilled in the absence of a significant increase in the level of funding available for research in this area. This danger, however, is probably best understood as a special case of a broader problem: the dramatic underfunding (relative to overall educational expenditure levels) of education research in general.[177]

The magnitude of the problem is illustrated by a (somewhat oversimplified) comparison between the American education system and the American pharmaceutical industry. In 1995, the United States spent about $70 billion on prescription and non-prescription medications, and invested about 23 percent of this amount on drug development and testing. By way of contrast, our nation spent about $300 billion on public K-12 education in 1995, but invested less than 0.1 percent of that amount to determine what educational techniques actually work, and to find ways to improve them.

Moreover, while pharmaceutical research expenditures have increased significantly over the past few decades as new technologies opened new avenues for medicinal innovation, research funded through the National Institute of Education[178] dropped by a factor of five (in constant dollars) between 1973 and 1986.[179] Although this situation has improved somewhat over the past decade, the Department of Education continues to allocate a relatively insignificant portion of its $30 billion annual budget to research.

In fairness, it should be noted that not all educational research is funded by the Department of Education. Funds are also allocated by the Defense Department, the National Science Foundation, the National Institutes of Health, and the National Institute for Mental Health for various forms of education-related research and evaluation. While some of these expenditures (NSF funding for research related to the teaching of science and mathematics at the elementary

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[177] Indeed, the trend toward viewing technology as a tool for the implementation of broader educational reform makes it difficult to separate research on educational technology from research on other aspects of education. Our concerns in this subsection will thus unavoidably extend beyond the boundaries of educational technology per se to encompass a number of aspects of education research in general.

[178] During the years in question, the NIE was the federal government's principal agency for education research.

[179] Based on data from U.S. General Accounting Office, *Education Information: Changes in Funds and Priorities Have Affected Production and Quality* (Washington, D.C., November 1987), p. 69, as reported in National Academy of Education, *Research and the Renewal of Education* (Stanford, CA: National Academy of Education, 1991), pp. 15-16.

and secondary school levels, for example) are directed toward K-12 education, however, much of the mission-oriented research conducted in these other agencies is less directly relevant.

State, local, and industrial support for research-related activities has for the most part been limited to functions that are unlikely to significantly advance the general state of knowledge within the field of education, including the collection of statistical data for administrative and planning purposes and for compliance with various statutory requirements, and support for local or statewide policy formulation. This phenomenon is easily accounted for by economic externalities analogous to those discussed in Section 8.3: Because no one state, municipality, or private firm could hope to capture more than a small fraction of the benefits associated with a fundamental advance in our understanding of the best way to educate elementary and secondary students in general, it would be unrealistic to expect such entities to conduct meaningful programs of basic research in education. While geographic decentralization may well be a useful heuristic in "reengineering" government for the more efficient execution of many public functions, the Panel believes this strategy to be generally inappropriate for the funding of research in either education in general or educational technology in particular.

Although modest funding for education research has historically been available through private foundations and corporate philanthropic programs, such institutions have in recent years tended to favor "action-oriented" programs over research and evaluation. In a 1991 report summarizing the findings of its Project on Funding Priorities for Educational Research, the National Academy of Education reported that "there is concern in the research community that numerous foundations are abandoning research in favor of demonstration projects with no research components whatsoever."[180]

In view of both the importance of elementary and secondary education to America's future and the enormous investment our nation makes in such education each year, the Panel recommends that after a brief transitional period involving substantial yearly increases, a steady-state allocation of no less than 0.5

[180] National Academy of Education, *Research and the Renewal of Education*, pp. 24-25.

percent of our nation's aggregate K-12 educational spending (or approximately $1.5 billion per year at present expenditure levels) be made to federally sponsored research aimed specifically at improving the efficacy and cost-effectiveness of K-12 education in the United States.

While this sum may seem quite large in absolute terms, when expressed as a fraction of total educational expenditures, it is some ten to twenty times lower than the comparable ratio in most knowledge-based industries. More importantly, because even a modest improvement in the cost-effectiveness of the educational process would result in an enormous reduction in the public expenditures required to achieve a given level of educational outcomes, the Panel believes that such an investment could result in substantial *savings* over time. Even these savings, however, would likely pale by comparison with the long-term dollar impact that a significantly improved K-12 educational system could be expected to have on our nation's economic competitiveness throughout the early decades of the twenty-first century.

Since technology is likely to be inextricably integrated throughout the new curricula arising from such investigations, it may be counterproductive to sequester all funds for educational technology research within a separate category, divorced from other aspects of educational research. Rather than propose a specific value for the technological component of such research, the Panel would thus offer only the qualitative recommendation that the use of computing and networking technologies be considered and, where appropriate, investigated *whenever* they might seem to be potentially useful in achieving the higher-level educational goals that motivate the educational research program proposed in this subsection.

## 8.5 Structural and Administrative Considerations

It should be noted that substantial federal funding is a necessary, but not a sufficient precondition for progress in understanding the ways in which technology might best be used to support K-12 education; also important is the manner in which the federal government structures and administers the research programs that are organized to effect such progress. As noted in Section 8.3, the Panel believes that such a research effort should include federal support for a relatively large number of small- and intermediate-scale projects managed independently by individual investigators and small teams. Such projects should be particularly valuable over the next few years, when early-stage, exploratory research is being conducted to generate hypotheses for rigorous empirical testing. While some degree of programmatic coordination may be useful to ensure adequate coverage of all relevant areas, the principal focus of such an early-stage program should be on extramural, investigator-initiated research, with grants and contracts awarded largely through a process of peer review by outside experts.

The Panel's emphasis on the importance of numerous independently conceived and executed research projects of relatively limited scale is not intended to discourage the provision of large-scale, sustained federal funding directed toward "centers of excellence" or other larger-scale programs; indeed, the "critical mass" associated with such centers and programs could well play an important role in catalyzing research progress in the field of educational technology. Such concentrated research efforts might be domiciled within academic institutions, research institutes, federal laboratories, or industrial sites, and might in some cases be distributed among a number of different geographic locations. Particular attention should be given to collaborative efforts that bring together universities and K-12 schools for experimental research situated within real classrooms—a type of project for which it is currently relatively difficult to secure funding.

Large-scale, coordinated projects will be particularly important in the later stages of research on the use of technology to support the objectives of educational reform, when hypotheses formulated during the early, exploratory phase are ready for rigorous, empirical evaluation. In order to draw reliable conclusions that can be used with confidence by educators and policy-makers, it will be necessary to systematically gather data from a large number of schools. To be maximally useful, such data should be collected in a well-coordinated, standardized manner (or at very least, should be sufficiently comparable to support meaningful meta-analyses based on all relevant studies). This will require the cooperation of a number of researchers and practitioners, and could be facilitated in important ways by programmatic coordination at the federal level. In the long term, important results should also be independently replicated under different conditions and by independent teams of investigators, adding further to the scope and scale of such an undertaking, and to the amount of data that will need to be collected within authentic classroom environments.

While the magnitude of these data requirements may appear to be quite formidable in absolute terms, it is actually very small relative to the enormity of America's K-12 student population. While some may object on principle to the use of our children as "guinea pigs," the reality is that such research could easily be organized in such a way as to involve only a small fraction of our nation's students, and to have a minimal impact on any single such student. Indeed, given the importance of elementary and secondary education, the substantial percentage of all public expenditures that are allocated to its support, and the widespread application of scientific methods to most other enterprises of comparable import, it is the *lack* of such experimentation that should perhaps be most alarming from a public policy viewpoint.

To pursue our earlier comparison along a different dimension, although some hundreds of thousands of Americans have been enrolled in FDA-approved trials designed to gather data on the safety and efficacy of new drugs, we have never undertaken an even remotely comparable effort to systematically collect the sort of data that might help us to evaluate the effectiveness of the educational techniques we are currently using to teach America's 51 million K-12 students. With suitable ethical controls[181] to ensure (among other things) that students are never subjected to experimental approaches believed to be inferior to current best practice, a wealth of scientific data could be collected on the efficacy of various approaches to the use of educational technologies by conducting trials within a relatively large, reasonably representative set of actual classrooms throughout the country. Even a small fraction of our nation's student population should be sufficiently large in absolute number to conduct numerous experiments with statistical power adequate to tease out all but the smallest effects. By failing to conduct such experiments, we are in effect wasting an immensely valuable source of data and foregoing an irreplaceable opportunity to improve our educational system materially over time.

Although quantitative considerations of the sort discussed above will play an important role in the formulation of federal policy for large-scale empirical re-

181 One possible starting point for the design of such controls might be the American Psychological Association's *Ethical Principles in the Conduct of Research with Human Participants* (Washington, D.C.: American Psychological Association, 1982), which in fact bear considerable similarity in some respects to those employed in FDA trials.

search on educational technology, research *quality* will be equally important. A concrete demonstration of what is attainable when the highest scientific standards are brought to bear on federally funded research in the area of educational technology is provided by the National Science Foundation, which is highly regarded both for the quality of the research it has supported in the field of educational technology (and in other, related areas) and for the manner in which funding decisions have been reached. While supporting a substantial increase in NSF-sponsored research on the use of technology in education,[182] the Panel believes it is also essential that comparable standards be maintained within the Education Department's Office of Educational Research and Improvement (OERI), whose present mandate with respect to K-12 education is broader in certain important respects than that of the National Science Foundation,[183] and within any other agency that is assigned responsibility for research relevant to elementary and secondary education.

To avoid the politicization and other problems which, in the past, have compromised the quality of research conducted under the auspices of OERI and its institutional predecessors,[184] concrete structural measures should be adopted to ensure the excellence, independence, and scientific integrity of all federally sponsored research on educational technology in particular and education in general. Specifically, the Panel recommends that the President appoint a board of distinguished outside experts to formulate an agenda for a coordinated, inter-agency program of rigorous scientific research in the field of education, and to oversee the execution of this program on an ongoing basis. The membership of such an oversight board should include not only educational researchers, but

182 This recommendation, however, is predicated on the assumption that such additional research would be funded through a corresponding increase in NSF's overall budget, and would not come at the expense of other important research programs now supported by the Foundation.

183 Certain sorts of research on the application of technology to subject areas other than science and mathematics, for example, fall more clearly within the province of OERI than that of NSF. As noted in Sections 4.6 and 8.3, the need for further work in these other areas is particularly urgent at present.

184 Fortunately, considerable attention has been given over the past several years to the strengthening of OERI, both by distinguished groups of outside experts and within the Department of Education itself. In this regard, it is worth noting that the Panel is generally supportive of the recommendations of the National Research Council's Committee on the Federal Role in Education Research (Richard C. Atkinson and Gregg B. Jackson, eds., *Research and Educational Reform: Roles for the Office of Educational Research and Improvement* (Washington, D.C.: National Research Council, 1992)) and of a number of proposals made by the National Academy of Education (National Academy of Education, *Research and the Renewal of Education*).

also leading researchers in other disciplines that might be relevant in terms of either content or methodology.

More generally, the Panel believes that substantially greater progress is likely to be made in expanding the current state of knowledge within the field of both education in general and educational technology in particular if research in these areas is conducted not only by investigators who are already working in the field of education, but also by highly qualified individuals trained in any of a wide range of other scientific, mathematical, or engineering disciplines. While it will be necessary for such individuals to acquire certain education-specific knowledge and skills, many of the research methodologies, conceptual frameworks, and technical skills associated with such disciplines are likely to prove transferable to the development and rigorous evaluation of innovative pedagogical methods. Moreover, the participation of substantial numbers of such individuals would seem likely to result in the infusion of new ideas into the educational research community and the promotion of high standards of methodological rigor within the field.

As it happens, American universities are currently producing more Ph.D.s in certain scientific, mathematical, and engineering disciplines than can be readily absorbed within the occupations for which they were trained, while many of our national laboratories are searching for new ways to productively deploy their respective pools of research talent. At such a time, the prospect of mobilizing a substantial corps of researchers trained in other fields to work with educators and educational researchers toward the systematic improvement of America's primary and secondary schools seems no less compelling than such multidisciplinary historical antecedents as the Manhattan Project or the space program. Federal support for such research efforts, and for graduate and post-doctoral training aimed at preparing individuals trained in other disciplines to conduct research applicable to K-12 education, could thus play an important role in achieving the research objectives outlined in this report.

Another important public policy question related to research on educational technologies is whether the deployment of computers and digital networks within our nation's schools should be delayed pending the availability of better data on the ways in which such technologies might be most effectively used. The Panel feels strongly that it would be a serious mistake to follow this course of action, however tempting that might appear from a fiscal perspective. While one might wish that an ambitious program of research on educational technologies had been launched several years ago, limitations in our current knowledge must not be used as an excuse to allow our schools to fall further behind other information-based institutions in their use of computing and networking technologies. In the words of Professor Chris Dede, "the most dangerous experiment we can conduct with our children is to keep schooling them the same at a time when every other aspect of our society is dramatically changing."[185]

[185] Professor Christopher Dede, written statement submitted to the PCAST Panel on Educational Technology, 1995, p. 2.

# 9. Programs and Policy

The future of educational technology in the United States will be determined not solely by the President and his various agents within the executive branch of government, but also by Congress, educators, the private sector, and the public at large. The charge of this panel, however, was defined more narrowly: While its members are hopeful that elements of this report may be of interest to various other readers as well, the Panel's primary objective has been to advise the White House on matters over which the President is capable of exerting at least some measure of control or influence. In this section, we briefly review some of the central elements of the Administration's current policy on educational technology, offering both feedback on current programs and suggestions as to the sorts of actions the President might wish to take in the future.

## *9.1 The President's Educational Technology Initiative*

In his State of the Union address on January 23, 1996, President Clinton announced the President's Educational Technology Initiative, which was formulated with the aim of ultimately achieving four top-level goals:

- **Computers:** "Modern computers and learning devices will be accessible to every student."
- **Connectivity:** "Classrooms will be connected to one another and to the outside world."
- **Content:** "Educational software will be an integral part of the curriculum—and as engaging as the best video game."
- **Educators:** "Teachers will be ready to use and teach with technology."[186]

[186] Executive Office of the President, "The President's Educational Technology Initiative," <http://www.whitehouse.gov/WH/EOP/OP/html/edtech/html/edtech.html>, 1996. See also U.S. Department of Education, *Getting America's Students Ready for the 21st Century: Meeting the Technology Literacy Challenge* (Washington, D.C., June 1996).

While the current report is organized somewhat differently for expository purposes, it will be noted that most of the areas the Panel has identified as critical to the successful deployment of educational technology are encompassed by the President's initiative. Moreover, the Panel's review of various documents generated by the White House, the Department of Education, the Committee on Education and Training of the National Science and Technology Council, the Office of Science and Technology Policy, and other sources within the executive branch suggests that the directions currently being pursued by the Administration are for the most part consistent with those the Panel believes to be most important. This impression has been reinforced in the course of formal briefings by and informal discussions with both federal officials and members of the educational technology community.

The most important respect in which the Panel believes the President's initiative should be fundamentally broadened and strengthened, however, relates to the pressing need for large-scale, federally sponsored research and evaluation, as discussed in Section 8. More generally, the Panel believes that it will be difficult for our nation to realize the full potential of educational technology in the absence of strong and substantive action at the federal level, the locus of which must necessarily extend far beyond the bully pulpit. Although certain activities may well be appropriate for execution at lower levels of government (as contemplated by several of the proposals discussed below), it is important that responsibilities not devolve to the states and municipalities that cannot, in fact, be efficiently or effectively discharged at those levels.

## *9.2 Funded Programs*

One program that has successfully leveraged a relatively small federal investment to provide substantial benefit within a number of communities is the Technology Learning Challenge, which provides funding to support the application of technology within American schools. The program awards five-year grants averaging $1 million each to local consortia headed by a board of education or other local education agency, but including other partners as well.[187]

[187] Other participants in a typical consortium might include hardware and software developers; telecommunication firms; libraries, museums, and community centers; state education agencies; colleges and universi-

Members of each consortium are expected to contribute substantially more than half of the support required for the proposed project,[188] resulting in the application of a substantial multiplier to any funds provided by the federal government.

The program places a strong emphasis on content and curricula, professional development, and the evaluation of educational effectiveness. As described in the program announcement, "Challenge Grants for Technology in Education are not about technology. Challenge Grants are about how to use technology to improve learning." Special preference is given to applications that "serve areas with a high number or percentage of disadvantaged students or other areas with the greatest need for educational technology," addressing some of the concerns expressed in Section 7. The program was inaugurated in 1995 with the award of 19 grants, selected (based on the recommendation of an external panel of experts) from among the proposals of some 530 applicants. The Panel strongly supports the continuation of the Technology Learning Challenge, and believes that it should be funded at a significantly higher level.[189]

Among the programs that together comprise the President's Educational Technology Initiative, the most ambitious in financial terms is the Technology Literacy Challenge, which was proposed by President Clinton on February 15, 1996. The focal point of this program is a proposed $2 billion Technology Literacy Fund that would be used to "catalyze and leverage state, local, and private sector efforts"[190] to meet the four goals outlined in Section 9.1. Funds would be

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ties; entertainment producers; and local businesses. In 1995, each funded consortium had an average of 20 such partners.

188 Indeed, the actual figure was in excess of 75 percent on average during the first year of the program's operation.

189 Apart from the opportunity cost associated with a missed opportunity to leverage the efforts of a larger number of communities, the unusually low funding ratio of this program implies an unusually large amount of time spent preparing grant applications that will ultimately prove unsuccessful. This effect may be mitigated in part by the substantial number of applicant consortia who, according to anecdotal reports, have continued to work toward the utilization of technology within their respective communities even after failing to secure federal support. It would be unfortunate, however, if budgetary constraints were to result in the funding of such a small percentage of all meritorious applications that the selection process assumed the character of a lottery.

190 Executive Office of the President, "America's Technology Literacy Challenge," http://www.whitehouse-.gov/WH/EOP/OP/html/edtech/html/edtech.html>, 1996. See also U.S. Department of Education, *Getting America's Students Ready.*

allocated to each state based on student enrollment, but would be subject to a one-to-one private sector matching requirement, which could take the form of volunteer time or discounted products and services as an alternative to cash contributions.[191] Each state would be given considerable flexibility in deciding how to achieve the goals of the President's Educational Technology Initiative. Provisions are also included for funding educational technology projects initiated by local communities or by consortia of private companies and local communities.

Though the Panel does not believe that either the Technology Challenge Grants or the Technology Literacy Challenge will in themselves be sufficient to realize the full promise of educational technology, it is nonetheless supportive of both of these programs, which it believes could play a particularly important role over the next few years—a period during which wide-ranging, exploratory experimentation with a number of different technological and pedagogic approaches is likely to prove most productive. As examples of apparently successful (or at least promising) applications of educational technology begin to emerge, however, it will become increasingly important to follow up on such anecdotal results with rigorous, systematic, large-scale experimentation to determine which approaches are in fact most effective and cost-effective.

While some states have in recent years been wary of nearly all forms of federal involvement in the education of their students, the Panel believes that the future welfare of *all* of our nation's students will be compromised if provisions are not made to ensure that individual states, localities, school districts, and schools cooperate in collecting the invaluable and irreplaceable data that is likely to be generated as a result of federally sponsored educational technology programs. Once sufficient data has been collected, funding will also be required for research aimed at analyzing and interpreting this data. Because no one state will be able to capture all of the benefits accruing from such studies, it is important that research funds be appropriated at the federal (and not the

[191] While matching programs of this sort are attractive to the extent they provide a mechanism for the use of federal dollars to lever resources mobilized by local communities to address locally perceived needs, it is important that consideration also be given to the needs of economically distressed communities whose needs may be particularly pressing, but which may have difficulty fulfilling such matching requirements, even with in-kind contributions.

state or local) level in order to avoid a systematic underinvestment relative to the economically optimal spending level, as discussed in Section 8.

The effort to incorporate technology within America's K-12 schools has also been directly or indirectly advanced by a number of other programs that have been initiated, supported, or promoted by the White House. The Telecommunications and Information Infrastructure Assistance Program, for example, which was created in 1994 within the Commerce Department's National Telecommunications and Information Administration, has provided federal matching funds (in partnership with state, local, and private sector sources) for local efforts to develop the information infrastructure available to schools and other public institutions. The Panel believes, however, that this program should be funded at a level sufficient to provide support for a larger percentage of those consortia whose applications are deemed meritorious.

From the viewpoint of educational technology, one of the most important pieces of recently enacted federal legislation is the Telecommunications Act of 1996,[192] which requires the Federal Communications Commission to revise the universal service system in such a way that elementary and secondary schools are provided with affordable access to advanced telecommunications services, including wide area network connectivity.[193] Although the discounting and/or other mechanisms through which such access will be ensured have yet to be finalized,[194] the Panel believes this legislation provides an unprecedented opportunity to address some of the most important problems outlined in Section 3.4.[195] The FCC has also recently issued a Notice of Proposed Rulemaking[196] in

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[192] Public Law 104-104, 110 Stat. 56, 1996.

[193] While the Act does not in fact authorize any additional direct spending on educational technology, we have included it in this section because its universal access provisions have essentially the same economic effect as an industry-specific tax whose revenues are targeted toward (among other things) the subsidization of educational networking costs, as discussed further in Footnote 195 below.

[194] The Act provided for the appointment by the FCC of a Joint Board consisting of three FCC commissioners, four State Public Utility Commissioners, and one consumer utility advocate to advise the Commission on the manner in which such universal service issues—including those relevant to the K-12 schools—should be addressed. The Joint Board's recommendations were submitted in November 1996, while completion of the FCC proceeding implementing these recommendations is scheduled for completion by May 8, 1997.

[195] In an ideal world, the Panel would in fact recommend that the funding required to connect America's schools to the Internet be derived not from an industry-specific cross-subsidy, but from general federal revenues. Indeed, from the viewpoint of economic theory, the universal access fund may be regarded as financed

response to private sector petitions for the allocation of a portion of the radio frequency spectrum to be used on an unlicensed basis in conjunction with new devices capable of providing wireless network connectivity within the nation's schools. Systems equipped with such devices could be especially valuable to those schools in which the presence of asbestos or other infrastructural challenges would otherwise make the cost of wiring particularly expensive.

Other existing federal programs address certain of the teacher-related needs identified in Section 5. The Department of Education's Regional Technology Consortia Program, for example, was designed to help educators (among others) to utilize technology through various forms of professional development, technical assistance, and information dissemination. The Educational Resources Information Clearing House (ERIC) service provides sample lesson plans, information related to educational reform, and answers to questions posed by teachers via electronic mail; while this program encompasses a number of other aspects of education as well, ERIC could potentially be of considerable value in helping educators to integrate technology into the curriculum.

## 9.3 Leadership and Coordination

In the present environment of fiscal austerity, tools available to the President for effecting change with little or no budgetary impact have assumed special importance. The Administration has thus far made considerable use of such tools, relying on the purposeful coordination of already-funded programs, the encouragement of extra-governmental efforts based largely on voluntarism, and the personal persuasive powers of the President and Vice President to leverage those aspects of the President's Educational Technology Initiative that will require the appropriation or redeployment of federal funding. While such activi-

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by a selective tax on the deployment (or equivalently, on the use) of telecommunications technologies, which should in principle be at least mildly counterproductive with respect to the goal of national competitiveness within an increasingly technology-intensive global economy. Given a political environment in which direct federal appropriations of this magnitude seem unlikely, however, the Panel views the funding mechanism specified in the Telecommunications Act of 1996 as a justifiable expedient, and is strongly supportive of its use to provide connectivity for the nation's schools.

[196] Federal Communications Commission, *Notice of Proposed Rulemaking: NII/SUPERNet at 5 Gz*, ET Docket No. 96-102, FCC 96-193, <http://www.fcc.gov/Bureaus/Engineering_Technology/Notices/fcc96193.txt>, 1996.

ties should not be regarded as a *substitute* for funded initiatives, the Panel believes these efforts should be continued.

One example in the first category is provided by the Committee on Education and Training (CET) of the National Science and Technology Council, which was established in part to promote the use of technology for education and training, and to coordinate the programs of the various federal agencies that currently engage in education-related research and development. The CET Subcommittee on Research and Development in Education and Training has identified four "focus areas" to be pursued on a coordinated cross-agency basis: the demonstration of innovative educational technology and networking applications; the formulation of new models for evaluating learning and learning productivity; the development of high-quality, affordable technology-based learning tools and environments; and research on learning and cognitive processes, with special emphasis on the ways in which technology might be used to best support the learning process.

Having reviewed the specific program elements defined within each of these areas and a few early examples of inter-agency cooperation in the development and application of educational technologies, the Panel is supportive of the CET Subcommittee's efforts. It is important, however, to recognize the limitations of an effort whose impact will be dependent in part on the sustained cooperation of a diverse group of mission-oriented agencies, and not to rely on such a working group as a substitute for a unified, large-scale, well-funded program in the area of educational technology R&D. While coordinative efforts of this sort can help to avoid the needless duplication of previously independent efforts and to facilitate the sharing of research tools and results, it would be unrealistic to expect such an effort to achieve by itself the objectives outlined in Section 8 of this report.

Another feature of the President's Educational Technology Initiative is its extensive reliance on both private firms and nonprofit organizations to help our nation's schools make effective use of computer and networking technologies. The White House has thrown its support, for example, behind a private sector organization called the Tech Corps, which was organized to coordinate the provision of technical assistance to the nation's schools by a network of volunteers in various communities throughout the country.[197] The President and Vice President have also met with a number of business leaders to enlist their support for the Administration's educational technology efforts, and both participated personally in NetDay96, a "high-tech barn-raising" event in which some 200 private companies and thousands of individual volunteers helped to wire a significant fraction of California's elementary and secondary schools to the Internet.[198]

The Panel believes that volunteer-based organizations and events of this sort can play an important role in introducing technology into our nation's classrooms—not only by contributing directly to the creation of essential infrastructure, but by calling public attention to the pressing technological (and other) needs of our nation's K-12 schools. It is again important, however, that important policy decisions not be made on the assumption that such voluntary efforts will greatly reduce the magnitude of the undertaking that will be required to effectively utilize computing and networking technologies within America's elementary and secondary schools on an ongoing basis. Although volunteers may well be able to assist in installing equipment on a one-time or short-term basis, securing the long-term commitments required to maintain and administer such systems may be more difficult, since interest in such purely voluntary efforts often wanes over time—particularly in the case of exciting, timely, event-oriented projects, which may generate a degree of initial enthusiasm that is difficult to sustain over a protracted period.

Even in the absence of such attrition, programs based on voluntarism can be expected to address only a subset of the human resource needs identified by the Panel in this report. While a not insignificant segment of the American workforce has acquired the sorts of technical skills that might be useful in the course of installing and operating a computer system, a much smaller number also possess the pedagogic expertise and the knowledge of available educational software that would be necessary to help a teacher learn to *use* such hardware effectively within a K-12 classroom environment. Excessive reliance on voluntary efforts may also exacerbate some of the problems of equitable ac-

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197 Tech Corps, <http://www.ustc.org>, 1996.

198 NetDay96, <http://www.netday96.com>, 1996.

cess discussed in Section 7; a rural school in a largely agricultural region, for example, may find it far more difficult to attract a large number of volunteers with the requisite knowledge of computer and networking technologies than one located in California's Silicon Valley or in the Route 128 area in Massachusetts. Notwithstanding these caveats, it seems clear that White House support has been helpful in mobilizing volunteers and other private sector resources to advance the cause of educational technology, and the Panel would encourage the continuation of such efforts as a complementary adjunct to funded programs.

Both the President and Vice President have assumed visible roles in promoting the use of the Internet by educational institutions, calling for the connection of all American classrooms to the Internet by the year 2000. More immediately, Vice President Gore has launched an initiative whose goal is the provision of Internet connections to all schools in the nation's Empowerment Zones—fifteen distressed communities in various urban and rural areas across the nation—thus addressing some of the most serious concerns expressed in Section 7. The Vice President also initiated the GLOBE program, which uses the Internet as a vehicle for involving students, teachers, and scientists around the world in the collaborative collection, exchange, and analysis of environmental data.

The President and Vice President have also used their respective offices to acknowledge (and thus direct attention toward) the efforts of those who have made particularly effective use of educational technology—an inexpensive policy tool which the Panel believes should continue to be exploited. Visits to "success story" schools like those identified in Section 2.3, along with physical (albeit largely symbolic) participation in voluntary projects, result in media coverage that helps to focus national attention on the potential significance of technology within an educational context. A similar effect obtains when the presidential imprimatur is conferred upon an organization like the American Technology Honor Society, which was created by the National Association of Secondary School Principals and the Technology Student Association to recognize and encourage the (sometimes surprisingly substantial) contributions of students themselves toward the incorporation of technology within their schools.

# 10. Summary of Findings and Recommendations

This section consists of a summary of the Panel's principal findings and an abbreviated list of general recommendations to the President. In the interest of brevity, however, and in order to highlight such information and advice as the Panel believes to be most important, this section does not include all of the detailed findings and recommendations incorporated within the full text of the Report.

## *10.1 Overview of the Panel's Findings*

While information technologies have had an enormous impact within America's offices, factories and stores over the past several decades, our country's K-12 educational system has thus far been only minimally affected by the information revolution. Although it is not yet possible to fully characterize the optimal ways in which computing and networking technologies might be used, the Panel believes that such technologies have the potential to transform our schools in important ways, and finds ample (albeit partially anecdotal) justification for the immediate and widespread incorporation of such technologies within all of our nation's elementary and secondary schools.

The Panel's assessment of current technology usage within America's elementary and secondary schools is outlined below, along with a discussion of some of the most formidable challenges that will have to be met if the promise of educational technology is to be realized.

### Hardware and Infrastructure

Significant investments will be necessary in hardware and infrastructure if educational technology is to be effectively utilized on a nationwide basis. American schools are now purchasing hardware at a relatively rapid rate, but the ratio of computers to students remains suboptimal from an educational viewpoint, and those machines which are available are often obsolete, and thus incapable of executing contemporary applications software. In addition, the computers in many schools are centralized within a single laboratory rather than distributed among the various classrooms, making it difficult for teachers to integrate technology within the curriculum.

Used equipment donated by corporations may be of value under certain circumstances, and may have collateral benefit to the extent such involvement helps to draw the private sector into closer contact with our schools. It should be noted, however, that the value of such donations (particularly when measured net of public revenue reductions associated with the corresponding federal and state tax deductions) may in other cases be offset by the increased maintenance costs and decreased utility typically associated with older machines, and by the need to integrate and support multiple platforms. Hardware donations are thus unlikely to obviate the need for a significant federal, state, and/or local investment in new equipment, and in the personnel-related expenditures (for installation, training, systems administration, user support, and hardware and software maintenance) that in fact account for the majority of the life-cycle cost of a computer system.

The inadequate physical and telecommunications infrastructure of our nation's schools poses another challenge for the effective exploitation of educational technologies. The optimal use of such technologies will require that computers be distributed throughout each school and interconnected through both local- and wide-area networks. The wiring systems in many school buildings, however, are incapable of supporting the electric power and data communications requirements of a modern networked computing environment. In some cases, the cost of retrofitting our schools for technology will be further increased by a lack of adequate air conditioning, by the presence of asbestos, and by various other factors. Wiring efforts based on the conscription of volunteers may be productive under certain circumstances within certain geographic areas, but cannot realistically be expected to make more than a relatively modest overall contribution toward solving the infrastructure and networking problems of America's schools.

## Software, Content and Pedagogy

While a significant investment in hardware and infrastructure will be required if the promise of educational technology is to be realized, the Panel believes that the effective *use* of these resources to improve our nation's educational system poses an even greater challenge. Even the earliest computer-aided instruction systems (typically used in a "drill-and-practice" mode to teach isolated facts and basic skills) provided the benefits of self-pacing and individualized instruction, and a number of studies have found such systems to offer significant improvements in learning rate, particularly within low-achieving student populations. In recent years, however, attention has increasingly focused on the ways in which technology might help to achieve some of the central objectives of educational reform, providing students with the ability to *acquire* new knowledge, to solve "real-world" problems, and to execute novel and complex tasks requiring the effective integration of a wide range of basic skills.

Within the framework of this newer paradigm, technology is viewed not as a tool for improving the efficiency of traditional instructional methods based largely on the unidirectional transmission of isolated facts and skills from teacher to student, but as one element of a new *constructivist* approach in which teachers concentrate instead on helping their students to actively construct their *own* knowledge bases and skill sets. This approach is typically characterized by the independent exploration of a limited number of topics in unusual (relative to traditional instructional methods) depth, and often relies on the availability of extensive information resources that can be drawn upon by the student as and when needed. Students may also use the computer as a tool for various forms of simulation; for written, musical, or artistic composition; for mathematical manipulation and visualization; for the design of various devices, environments, and systems; for the acquisition of computer programming skills; for the collection and analysis of laboratory data; for many forms of problem-solving; and for various modes of group collaboration.

Neither the constructivist pedagogic model nor the proposed role of technology within a constructivist curriculum has yet been validated through a process of extensive, rigorous, large-scale experimentation, and it is quite possible that alternative approaches may ultimately be found useful as well. This caveat notwithstanding, a combination of theoretical considerations (based in part on research in cognitive psychology and other fields) and the observation of a limited number of apparent "success stories" suggest that computing and networking technologies could potentially find their most powerful application within the framework of the constructivist paradigm.

While the role of the teacher is likely to change within a technology-rich constructivist classroom, the Panel found no evidence to suggest a *diminution* of that role. Preliminary research suggests that the potential benefits of such an environment decline as class size increases, and that teachers will still be required to play an important role in helping students to assimilate abstract concepts and develop higher-order thinking skills. Teachers can be expected to spend a great deal of time monitoring, directing, and assisting in the (largely self-directed) learning process, and helping to "debug" faulty "mental models." There is some (again preliminary) evidence that students spend more time interacting with teachers and other students within the technology-rich classroom, calling into question the intuitively plausible notion that computers might interfere with the acquisition of valuable social and collaborative skills. Technology may also improve educational outcomes by supporting various forms of interaction with parents and the community.

While the greatest promise of educational technology lies in the possibility of utilizing computers and networks as an integral part of virtually all aspects of the curriculum, most of the elementary and secondary schools that actually use such technologies today do so in far more limited ways. A large fraction of current usage—especially at the high school level—is accounted for by "computer education," which aims to teach students *about* computers (focusing, for example, on the acquisition of keyboarding skills; instruction in the use of word processing, database management, spreadsheet, and other software tools; and the study of computer programming) rather than *using* computers as a tool for learning in *all* subject areas. Educational games and instruction in isolated basic skills also account for a significant portion of current usage—particularly within the elementary school—but few schools have integrated computing and networking technologies extensively and effectively into the learning process, or used it as a key element of educational reform.

One obstacle to the effective integration of information technology is a dearth of state-of-the-art software and digital content designed for the K-12 school environment. A plateau in the sales of traditional Integrated Learning Systems has led to a precipitous decrease in R&D spending by ILS vendors at a time when education reform is placing new demands on such systems. Moreover, neither traditional vendors nor newly organized firms have thus far invested in the development of software suitable for use within a constructivist curriculum to the extent that will be required to effectively cover a wide range of content areas (especially at the secondary school level) and skill levels. Among the apparent reasons for these market problems are weak incentives for private sector R&D (resulting from inadequate software acquisition budgets and various forms of market fragmentation); lack of modern hardware within the schools; peculiarities in the procedures used for software procurement; and inadequate federal funding for innovative early-stage research whose benefits cannot be appropriated by any one company, and which is thus unlikely to be conducted without public sector involvement—an economic externality sometimes referred to as the "free rider" problem.

## Teachers and Technology

In order to effectively integrate new technologies into the curriculum, teachers will have to select appropriate software, construct new lesson plans, resolve a number of logistical problems, and develop appropriate methods of assessing student work. The Panel finds, however, that our nation's K-12 teachers currently receive little technical, pedagogic or administrative support for these activities, and that few colleges of education adequately prepare their graduates to use information technologies in their teaching.

Contributing to this problem is the fact that only about 15 percent of the typical computer budget is devoted to professional development, compared with the 30 percent or more that is generally believed to represent a more optimal allocation. Moreover, most of these expenditures are aimed at training teachers to *operate* a computer, rather than to use computers to enhance their *teaching*. In addition, many teachers do not have adequate access to technological and pedagogical support on an ongoing, "as-needed" basis. Fewer than five percent of all schools have full-time computer coordinators capable of providing such sustained assistance, and such coordinators as are available typically spend only 20 percent of their time helping teachers, selecting software, or formulating technology-oriented lesson plans.

Fortunately, technological progress may itself contribute toward the solution of some of the problems of professional development by making educational software easier for teachers to use; by helping teachers in various ways to recover some of the time invested in the introduction of technology; and by supporting online professional development seminars and remote mentoring and consulting activities, which the Panel believes are likely to prove significantly more cost-effective than conventional instruction under appropriate circumstances.

Perhaps the greatest single factor now holding back the adequate preparation of teachers is a lack of sufficient time in their work week to effectively incorporate technology into the curriculum. Unless additional time can be made available by eliminating or de-emphasizing other, less critical tasks, however, each hour set aside in the school week for technology-related curricular design and professional development can be expected to (directly or indirectly) add between $4 and $5 billion to our nation's yearly expenditures for K-12 education. Moreover, research reviewed by the Panel suggests that the typical teacher will require between three and six years to fully integrate technology into his or her teaching; in the presence of continued technological innovation, a teacher's learning curve is thus unlikely to *ever* level off entirely.

While America's colleges of education have the potential to play an invaluable role in preparing our teachers to use technology effectively in their professional activities, information gathered by the Panel suggests that most education schools are still far from realizing that potential. Although pre-service instruction in the use of technology is required by 22 states (in contrast with only two states that require in-service training), the courses used to satisfy such requirements typically provide no actual experience in using computers to teach, and impart little knowledge of available software and content.

In order to prepare our teachers for the effective use of technology, education schools will have to overcome some of the same problems now encountered by our nation's K-12 schools: inadequate funding for the acquisition of hardware and software; a paucity of programs aimed at providing education school faculty members with the background necessary to prepare future teachers in the use of technology; and the lack of sufficient time for professors of education to incorporate technology within both the content and methods of their courses.

## Economic Considerations

Based on currently available data, the Panel estimates that public elementary and secondary schools in the United States spent between $3.5 and $4 billion on educational technology during the 1995-96 school year, including investments in hardware, wiring, infrastructural enhancements, software and digital information resources, systems support, and technology-related professional development. This figure, which represents about 1.3 percent of projected total spending in our schools, is extraordinarily low by comparison with most other information-based industries, and in the opinion of the Panel, will have to rise significantly if technology is to have a material impact on the quality of American education.

By way of contrast with these current expenditure figures, the seven studies reviewed by the Panel suggest that annual expenditures of between $6 billion and $28 billion (or between 2.4 and 11.3 percent of total educational spending) will likely be required to adequately support various degrees of technology usage within the public schools, and that even those spending levels will be insufficient to support the sort of technology usage that might be considered optimal if cost were not an issue. Because computing and networking hardware will account for only a minority of this spending, educators and policy-makers will not be able to rely solely on one-time bond issues and private capital campaigns of the sort often used to finance the construction of school buildings, and will have to budget for substantial ongoing operating expenditures if they are to avoid a situation in which valuable hardware is left unused.

Based on models from other industries, it seems likely that further experience with the use of technology in our schools could ultimately result in significant improvements over time in the educational outcomes achievable at a given level of expenditure. Such improvements, however, are likely to be critically dependent on rigorous, large-scale programs of research and evaluation aimed at assessing the efficacy and cost-effectiveness of various approaches to the use of technology in actual K-12 classrooms.

Most importantly, educational technology expenditures are best analyzed not on the basis of cost alone, but in terms of return on investment. While it would be difficult to quantify all of the benefits that might be derived from the use of educational technology, the Panel believes that a substantial investment in technology may be justifiable even if *no* value is placed on the direct (economic and non-economic) benefits accruing to the American people, using return calculations based solely on projected marginal tax revenues associated with an increase in their expected lifetime taxable earnings.

## Equitable Access

Educational technologies have the potential to either ameliorate or exacerbate the growing gulf between advantaged and disadvantaged Americans, depending on policy decisions involving the ways in which such technologies are deployed and utilized on behalf of various segments of our country's student population. Although federal programs have played a major role in limiting certain inequities, disparities in the access to and use of information technologies by students of different socioeconomic status (SES), race and ethnicity, gender, and geographical location, and by children with various types of special needs, remain a source of concern to the Panel.

Income-related inequities in the number of students per in-school computer have narrowed significantly over the past decade, largely as a result of Title I spending, which provided about $2 billion in federal funding over that period for the provision of educational technology within low-income schools. Low-SES students, however, still use computers less extensively in school, and are less likely to use computers for higher-order learning activities, than their higher-income peers. Such disparities may be accounted for in part by differences in the preparation and support available to teachers at more and less affluent schools.

The largest SES-related inequities, however, are found in the availability of computers within the home: Whereas computers were found in 73 percent of all homes with college-educated parents and more than $50,000 in annual household income in 1995, they were present in only 14 percent of all households headed by adults having no more than a high-school education and a combined income of less than $30,000. Since school-aged children in homes with computers frequently use these machines for schoolwork or other educational purposes, these SES-related disparities in home computer ownership materially limit the educational opportunities available to low-income students, and thus help to perpetuate familial patterns of socioeconomic disadvantage.

As in the case of socioeconomic status, Title I funding has helped to reduce, but not eliminate, racial and ethnic disparities in the access to computers within the school. Hispanic students, in particular, attend schools with an unusually low density of computers, especially at the elementary school level. Once again, however, the disparity is even greater within the home. As of 1993, for example, the rate of computer ownership was 57 percent lower in African-American homes, and 59 percent lower within Hispanic households, than in the homes of non-Hispanic whites. While a portion of this gap is accounted for by differences in socioeconomic status, differences of 36 percent and 39 percent, respectively, remain even after controlling for household income, educational attainment, age, gender, and location of residence (urban or rural). Race and ethnicity thus represent an independent source of inequity in children's access to educational technology—a source of additional concern to the Panel.

Although certain regional differences are apparent in the use of computers, in-school computer density is roughly comparable across the nation's Western, Midwestern, Northeastern and Southern regions. Rural schools enjoy a significantly higher density than their urban counterparts, but this difference would appear to be largely explained by the fact that rural schools are smaller on average, and smaller schools tend to have a higher computer density. While the available statistics do not support a definitive quantitative comparison of different types of urban environments, anecdotal evidence suggests that inner city schools may face special problems in making effective use of educational technology, as may rural schools in certain areas where wide area networking is rendered more expensive by a lack of economical telecommunications access.

Gender-specific variation in the *extent* of computer use is relatively small in magnitude, both in school and at home, but certain systematic differences are found in the *ways* in which boys and girls use computers. Although research has shown that high school girls make 50 percent greater use of the computer for word processing than their male classmates, for example, they have been found to account for only 26 percent of all elective computer use before and after school, and for only 20 percent of all in-school computer-based game-playing activities. There is also some evidence that girls and boys engaging in computer-related learning activities may differ in their relative responses to co-operative, competitive, or individualistic reward structures—a phenomenon which, if validated, could have implications for both the design of optimal pedagogical methods for and the provision of equitable access to male and female K-12 students.

One less obvious form of inequity involves the accessibility of educational technology to low-achieving students. The available data indicates that students with higher grades are allowed more in-school computer time than their underperforming peers, in spite of a substantial body of evidence suggesting that technology may in fact be of *greater* relative benefit to low-achieving than to high-achieving students. This disparity is compounded by the fact that when underperforming students do use computers, they are more likely than high achievers to engage in drill and practice on isolated basic skills, and less likely to use computers for tasks involving the acquisition and integration of a wide range of knowledge—a practice that runs counter to the recommendations of many educational technology researchers.

Technology also has the potential to significantly improve the educational opportunities available to many American students with learning disabilities, behavior disorders, emotional problems, or physical disabilities. The realization of this potential, however, will depend in part on the widespread availability of special input, output, and other devices, and of teachers and support personnel who have the training necessary to effectively deploy such technologies. The case for federal involvement in mobilizing technology on behalf of students with special needs rests in part on the observation that within a typical school district (and in the case of certain less common disabilities, even within a given state), the number of students with a given disability is likely to be too small to adequately amortize the cost of researching, developing, and effectively deploying the assistive technologies that would provide appropriate educational support for those students.

## Research and Evaluation

Both the enormous importance and the enormous cost of K-12 education in the United States argue for careful research on the ways in which computing and networking technologies can be used to improve educational outcomes and the ratio of benefits to costs. The majority of the empirical research reported to date has focused on traditional, tutorial-based applications of computers. Several meta-analyses, each based on dozens of independent studies, have found that students using such technology significantly outperform those taught without the use of such systems, with the largest differences recorded for students of lower socioeconomic status, low-achievers, and those with certain special learning problems. While certain methodological and interpretive questions have been raised with respect to these results, the most significant issue may be the question of whether the variables being measured are in fact well correlated with the forms of learning many now feel are most important.

Although constructivist applications of technology are intended to more directly support the goals of the current educational reform movement, research on such applications is still at a relatively early stage. Most of the work in this area is formative in nature, intended more as a preliminary exploration of new intellectual territory than a definitive evaluation of any one possible solution. Although some interesting and potentially promising empirical results have been reported in the literature, a substantial amount of well-designed experimental research will ultimately be required to obtain definitive, widely replicated results that shed light on the underlying sources of any positive effects, and which are sufficiently general to permit straightforward application within a wide range of realistic school environments.

One important issue that arises in this context is the manner in which "favorable" educational outcomes are defined and measured for purposes of evaluating the relative effectiveness of alternative approaches to the use of technology. Conventional, standardized multiple-choice tests have certain advantages, but tend to emphasize the accumulation of isolated facts and basic skills, and not the acquisition of higher-order thinking and problem-solving competencies of the sorts that are central to both the constructivist paradigm and the goals of contemporary educational reform. Since researchers, educators and software developers can be expected to develop content and techniques that optimize student performance with respect to whatever criteria are employed to measure educational attainment, progress within the field of educational technology will depend critically on the development of metrics capable of serving as appropriate and reliable proxies for desired educational outcomes.

While research in a wide range of areas could directly or indirectly facilitate the effective utilization of educational technology within our nation's K-12 schools, much of the research that the Panel believes to be most important falls into one of the following three categories:

1. Basic research in various learning-related disciplines (including cognitive and developmental psychology, neuroscience, artificial intelli-

gence, and the interdisciplinary field of cognitive science) and fundamental work on various educationally relevant technologies (encompassing in particular various subdisciplines of the field of computer science)

2. Early-stage research aimed at developing innovative approaches to the application of technology in education which are unlikely to originate from within the private sector, but which could result in the development of new forms of educational software, content, and technology-enabled pedagogy, not only in science and mathematics (which have thus far received the most attention), but in the language arts, social studies, creative arts, and other content areas

3. Rigorous, well-controlled, peer-reviewed, large-scale (and at least for some studies, long-term), broadly applicable empirical studies designed to determine not *whether* computers can be effectively used within the school, but rather *which* approaches to the use of technology are in fact most effective and cost-effective in practice

To date, however, research on educational technology (and indeed, on education in general) has received minimal funding—particularly when measured relative to our nation's expenditures for K-12 education, which currently total more than a quarter trillion dollars per year. By way of comparison, whereas some 23 percent of all U.S. expenditures for prescription and non-prescription medications were applied toward pharmaceutical research in 1995, less than 0.1 percent of our nation's expenditures for elementary and secondary education in the same year were invested to determine what educational techniques actually work, and to find ways to improve them.

Research funded by the National Institute of Education dropped by a factor of five (in constant dollars) between 1973 and 1986, and although steps have recently been taken to ameliorate the severity of this decline, federal funding continues at a small fraction of the level that would seem appropriate even if our goal were solely to minimize ongoing expenditures by enhancing cost-effectiveness, without any attempt to improve educational outcomes. State, local, and industrial support for educational research has for the most part been limited to functions that are unlikely to significantly advance the general state of knowledge within the field, a reflection of intrinsic economic externalities that will not be overcome in the absence of funding at the highest level of taxing authority. Moreover, private foundations and corporate philanthropic programs have in recent years tended to favor "action-oriented" programs over research and evaluation, leaving no obvious alternative to pick up the slack left by inadequate federal funding.

Quality control problems affecting the administration of federal research programs in the field of education have historically presented another obstacle to progress in the field of educational technology. While certain programs (most notably, those overseen by the National Science Foundation) have generally adhered to high standards of excellence, independence, and scientific integrity, others (including the Office of Educational Research and Improvement and its institutional predecessors) have in the past been adversely affected by counterproductive political influence and other problems. Fortunately, considerable attention has been given over the past several years to the strengthening of OERI, which enjoys a broader mandate in some respects than the NSF, and could thus play an important role in advancing our nation's understanding of the potential applications of technology to K-12 education.

## Programs and Policy

The President's Educational Technology Initiative, which was announced in President Clinton's January 1996 State of the Union address, was designed to achieve four goals which the Panel believes will indeed be central to realizing the promise of educational technology: providing our schools with the modern computer hardware, local- and wide-area connectivity, high quality educational content, and appropriate teacher preparation that will be necessary if information technologies are to be effectively utilized to enhance learning. This initiative serves as an umbrella for a number of distinct, but interrelated programs aimed at achieving these four goals within a relatively ambitious time frame.

One Administration program that has already shown considerable promise is the Technology Learning Challenge, which awards five-year matching grants averaging $1 million each to help local consortia (typically consisting of private and public sector partners) to apply technology within schools in their respective areas. Although the overall impact of this program will be limited by funding constraints, these grants would appear to represent an excellent example of the effective leveraging of federal dollars in support of high-quality, locally-initiated efforts to improve education through the use of computing and communications technologies.

In February 1996, President Clinton also proposed a program called the Technology Literacy Challenge, which would create a $2 billion Technology Literacy Fund that would be used to "catalyze and leverage state, local, and private sector efforts" to meet the four goals outlined above. Federal funds would be allocated to the states (or under certain circumstances, local communities), which would be given considerable flexibility in deciding how to achieve the goals of the President's Educational Technology Initiative. If enabling legislation is in fact enacted, the Panel believes that this program is indeed likely to significantly advance the objectives outlined by the President, particularly during an initial period in which wide-ranging, exploratory experimentation with a number of different technological and pedagogic approaches is likely to prove most productive.

The Panel also believes, however, that a large-scale, rigorously controlled, federally sponsored program of research and evaluation will ultimately be necessary if the full potential of educational technology is to be realized in a cost-effective manner. Data gathered systematically by individual states, localities, school districts, and schools during an initial phase of federally supported educational technology efforts could prove invaluable in determining which approaches are in fact most effective and economically efficient, thus helping to maximize the ratio of benefits to costs in later phases. Federal funding will ultimately also be required for research aimed at analyzing and interpreting this data.

The effort to incorporate technology within America's K-12 schools has also been directly or indirectly advanced by a number of other programs that have been initiated, supported, or promoted by the White House, including the Commerce Department's Telecommunications and Information Infrastructure Assistance Program, which provides federal matching funds to develop the information infrastructure available to schools; the Telecommunications Act of 1996, which requires the Federal Communications Commission to revise the universal service system in such a way that elementary and secondary schools are provided with affordable access to advanced telecommunications services; and the Department of Education's Regional Technology Consortia Program, which was designed to help educators (among others) to utilize technology through various forms of professional development, technical assistance, and information dissemination.

Responding to current pressures for fiscal restraint, the Clinton Administration has also made effective use of extra-budgetary tools, relying on the purposeful coordination of already-funded programs, the encouragement of extra-governmental efforts based largely on voluntarism, and the personal persuasive powers of the President and Vice President to leverage as extensively as possible those aspects of the President's Educational Technology Initiative that will require the appropriation or redeployment of federal funding. One example in the first category is provided by the activities of the Committee on Education and Training of the National Science and Technology Council to promote the use of technology for education and training, and to coordinate the programs of the various federal agencies that currently engage in education-related research and development.

The second category of extra-budgetary leadership is exemplified by Presidential and Vice Presidential support for the Tech Corps, a private sector organization organized to coordinate the provision of volunteer technical assistance to the schools, and for NetDay96, a "high-tech barn-raising" event in which private companies and individual volunteers helped to wire a significant fraction of California's elementary and secondary schools to the Internet. While the Panel believes that it would be unrealistic to expect such purely voluntary efforts to dramatically reduce the dollar cost of effectively utilizing educational technologies on an ongoing basis, it seems clear that such efforts can play an important supporting role, not only directly, but also by calling public attention to the pressing technological (and other) needs of our nation's K-12 schools.

Both President Clinton and Vice President Gore have assumed leadership roles in promoting the use of the Internet by educational institutions, calling for the connection of all American classrooms to the Internet by the year 2000, with special emphasis on economically distressed areas. The President and Vice President have also made effective use of their respective offices to acknowledge (and thus direct attention toward) the efforts of those who have made particularly effective use of educational technology. While some of the objectives outlined in this report cannot be achieved by the President alone, and will require the appropriation or redeployment by Congress of substantial funds, the Panel believes that the Clinton Administration has thus far done an excellent job of addressing such needs as can be satisfied in the absence of such funding.

## *10.2 Principal Recommendations*

The body of this report includes a number of relatively specific recommendations related to various aspects of the use of technology within America's elementary and secondary schools. In order to focus attention on a limited number of high-level strategic (as opposed to tactical) issues which the Panel believes to be most important, however, much of this detail is omitted from the summary of selected recommendations that follows.

1. **Focus on learning *with* technology, not *about* technology.** Although both are worthy of attention, it is important to distinguish between technology as a subject area and the *use* of technology to facilitate learning about *any* subject area. While computer-related skills will unquestionably be quite important in the twenty-first century, and while such skills are clearly best taught through the actual use of computers, it is important that technology be integrated *throughout* the K-12 curriculum, and not simply used to impart technology-related knowledge and skills. Although universal technological literacy is a laudable national goal, the Panel believes the Administration should work toward the use of computing and networking technologies to improve the quality of education in *all* subject areas.

2. **Emphasize content and pedagogy, and not just hardware.** The widespread availability of modern computing and networking hardware will be *necessary* for technology to realize its promise, but will not be sufficient. Although the purchase of computers and the provision of Internet connectivity are perhaps the most visible and most easily understood manifestations of progress, a less obvious (and in some ways, more formidable) challenge will be the development and utilization of demonstrably useful educational software and information resources, and the adaptation of curricula to make effective use of technology. Particular attention should be given to exploring the potential role of technology in achieving the goals of current educational reform efforts through the use of new pedagogic methods based on a more active, student-centered approach to learning that emphasizes the development of higher-order reasoning and problem-solving skills.

While obsolete and inaccessible computer systems, suboptimal student/computer ratios, and a lack of appropriate building infrastructure and network connectivity will all need to be addressed, it is important that we not allow these problems to divert attention from the ways in which technology will actually be *used* within an educational context.

3. **Give special attention to professional development.** The substantial investment in hardware, infrastructure, software and content that is recommended in this report will be largely wasted if K-12 teachers are not provided with the preparation and support they will need to effectively integrate information technologies into their teaching. At least 30 percent of all federal expenditures for educational technology should be allocated to professional development and to ongoing mentoring and consultative support for teachers. Schools and school districts should be encouraged to provide time for teachers to familiarize themselves with available software and content, to incorporate technology into their lesson plans, and to discuss technology use with other teachers. Finally, both presidential leadership and federal funding should be mobilized to help our nation's schools of education to incorporate technology within their curricula so they are capable of preparing the next generation of American teachers to make effective use of technology.

4. **Engage in realistic budgeting.** The Panel believes that at least five percent of all K-12 educational spending in the United States, or approximately $13 billion annually (in constant 1996 dollars), should be earmarked for technology-related expenditures. Because the amortization of initial acquisition costs will account for only a minority of these recommended expenditures, schools should be encouraged to incorporate technology within their ongoing operating budgets rather than relying solely on one-time bond issues and capital campaigns. While voluntarism and corporate equipment donations may also be of both direct and indirect benefit under certain circumstances, White House policy should be based on a realistic assessment of the relatively limited direct economic contribution such efforts can be expected to make overall. The President should continue to make the case for educational technology as an investment in America's future, while seeking to enhance the return on that investment by promoting federally sponsored research aimed at improving the cost-effectiveness of technology usage within our nation's elementary and secondary schools.

5. **Ensure equitable, universal access.** The Panel feels strongly that access to knowledge-building and communication tools based on computing and networking technologies should be made available to *all* of the nation's students, regardless of socioeconomic status, race, ethnicity, gender, or geographical factors, and that special attention should be given to the use of technology by students with special needs. Equity should be a central consideration in all federal programs dealing with the use of technology in education. In particular, Title I spending for technology-related investments on behalf of economically disadvantaged students should be maintained at no less than its current level, with ongoing adjustments for inflation, expanding U.S. school enrollment, and projected increases in overall national spending for K-12 educational technology. Because much of the educational use of computers now takes place within the home, and because the rate of home computer ownership diverges alarmingly for students of different race, ethnicity, and socioeconomic status, consideration should also be given to public policy measures designed to reduce disparities in student access to information technologies outside of school.

6. **Initiate a major program of experimental research.** In view of both the critical importance of and massive expenditures associated with K-12 education in the United States, the Panel recommends that an amount equal to at least 0.5 percent of the nation's aggregate spending for elementary and secondary education (about $1.5 billion at current expenditure levels) be invested on an ongoing basis in federally sponsored research aimed at improving the efficacy and cost-effectiveness of K-12 education. Because no one state, municipality, or private firm could hope to capture more than a small fraction of the benefits associated with a significant advance in our understanding of how best to educate K-12 students, this funding will have to be provided largely at the federal level in order to avoid a systematic underinvestment (attributable to a classical form of economic externality) relative to the level that would be optimal for the nation as a whole.

   To ensure high standards of scientific excellence, intellectual integrity, and independence from political influence, this research program should be planned and overseen by a distinguished independent board of outside experts appointed by the President, and should encompass (a) basic research in various learning-related disciplines and on various educationally relevant technologies; (b) early-stage research aimed at developing new forms of educational software, content, and technology-enabled pedagogy; and (c) rigorous, well-controlled, peer-reviewed, large-scale empirical studies designed to determine which educational approaches are in fact most effective in practice. The Panel does *not*, however, recommend that the deployment of technology within America's schools be deferred pending the completion of such research.

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