Power On! New Tools for Teaching and Learning

September 1988

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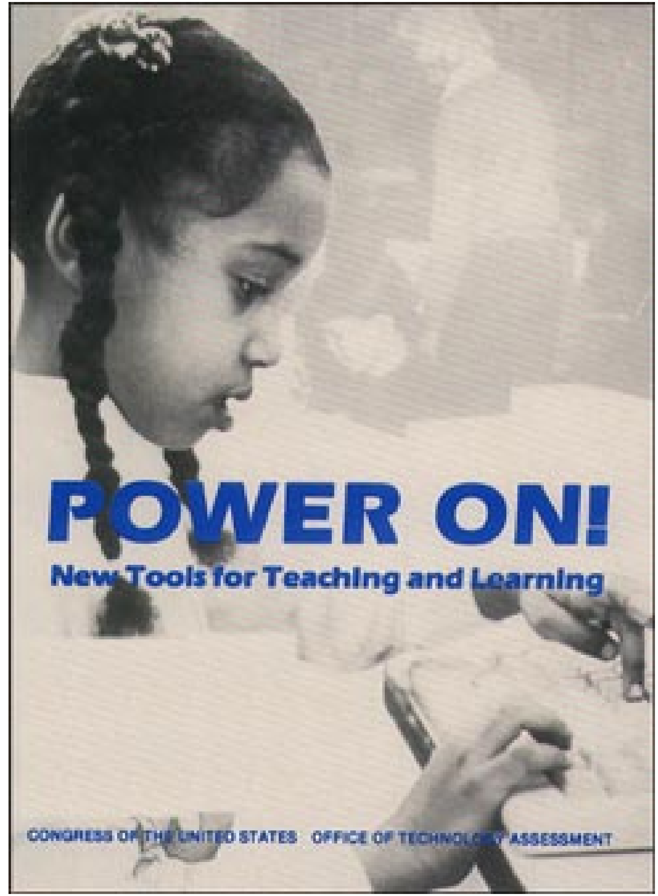

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Foreword

It has been less than a decade since the first personal computers appeared on the education scene. Schools have acquired computers rapidly since then, but most elements of the instructional process remain the same. This contrasts with other sectors of society, where technology has changed the way business is transacted, medical problems are analyzed, and products are produced. During this same decade, calls for improving the quality of education for all children have increased. To better understand the potential of new interactive technologies for improving learning, the House Committee on Education and Labor, and its Subcommittee on Select Education, asked the Office of Technology Assessment to do this study.

Teachers, administrators, parents, software publishers, hardware manufacturers, researchers, policy makers at all levels of government, and students all play a role in turning on the power of new tools for teaching and learning. This report examines developments in the use of computer-based technologies, analyzes key trends in hardware and software development, evaluates the capability of technology to improve learning in many areas, and explores ways to substantially increase student access to technology. The role of the teacher, teachers' needs for training, and the impact of Federal support for educational technology research and development are reviewed as well.

Throughout this study, the Advisory Panel, workshop participants, and many others played key roles in defining major issues, providing information, and championing a broad range of perspectives. OTA thanks them for their substantial commitment of time and energy. Their participation does not necessarily represent an endorsement of the contents of the report, for which OTA bears sole responsibility.

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NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the advisory panel members. The panel does not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

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Related OTA Reports

- *Trends and Status of Computers in Schools: Use in Chapter 1 Programs and Use with Limited English Proficient Students.*
  OTA Staff Paper, March 1987, 129 pages.
  NTIS order #PB 87-176723
- *Educating Scientists and Engineers: Grade School to Grad School.*
  OTA-SET-377, June 1988, 136 pages.
  GPO stock #052-003-01 110-7
- *Elementary and Secondary Education for Science and Engineering.*
  OTA-TM-SET-41, to be published fall 1988.
- *Technology and the American Economic Transition: Choices for the Future.*
  OTA-TET-283, May 1988, 512 pages.
  GPO stock #052 -003-01096-8
- *Intellectual Property Rights in an Age of Electronics and Information.*
  OTA-CIT-302, April 1986, 300 pages.
  NTIS order #PB 87-100 301/AS
- *information Technology R&D: Critical Trends and Issues.*
  OTA-CIT-268, February 1985, 352 pages.
  GPO stock #052 -003-00976-5
- *Informational Technology and Its Impact on American Education.*
  OTA-CIT-187, November 1982, 280 pages.
  GPO stock #052 -003-00888-2

NOTE: Reports are available through the U.S. Government Printing Office, Superintendent of Documents, Washington, DC 20401-9325, (202) *783-3238;* and/or the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161-0001, (703) 487-4650.

Chapter 1

Summary

Photo credit: West High School, Columbus, Ohio

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Summary

INTRODUCTION

At Poteet High School in Mesquite, Texas, ninth grade students are doing experiments with radioactive materials, handling explosives, and pouring sodium metal into a lake, and their teachers think it's great! With their entire physical science curriculum–160 hours of instruction, one semester of chemistry and one of physics—on interactive videodisc, they are learning about and doing science in a simulated environment. The laser videodisc combines the drama of a television program with the capabilities of a computer: a touch of a computer screen brings to life a volcanic eruption or a solar flare.[1]

The fifth grade class at Sacred Heart Model School in Louisville, Kentucky, recently assembled a computer database of their pets: 25 dogs, 15 cats, 13 hamsters and gerbils, 5 horses, 4 hermit crabs, 1 guinea pig, 3 each of rabbits, turtles, and chickens, and 73 fish. Updates and comparisons are expected, as the class shares information with students who live in other cities, in suburban communities, and in rural areas. Their next project is to test the acidity of the city's tap water and compare their results with data from 199 other schools around the world via telecommunications.[2]

A librarian in Jefferson County, Alabama, spent her spring vacation driving a group of junior high school students around the State, where they videotaped historical sites, agriculture and industries, tourist attractions, and the Governor at work in the capital. The students are creating their own curriculum materials for a course on "Our Alabama Heritage."[3]

In most other classrooms, teachers stand in front of a blackboard, chalk in hand, lecturing as teachers always have. Some students take notes on paper; others look out the window, as students always have. Are the Poteet High, Sacred Heart, or Jefferson County classrooms isolated cases, or are they realistic previews of how new information technologies will change all schools?

Today's classrooms typically resemble their ancestors of 50 years ago more closely than operating rooms or business offices resemble their 1938 versions. But new technologies are making possible imaginative approaches to teaching traditional subjects and are motivating teachers and children to try new ways of information gathering and learning.

New learning tools have diverse objectives and effects. This diversity is due, in part, to the flexibility of interactive technologies.[4] Computers help teach children to read, write, and "do sums." Telecommunications lets students in remote areas, who might otherwise be denied access, take advanced classes in calculus, foreign language, and physics. Science students use computer-based measurement instruments, while their classmates use simulation programs to "participate" in politics and history. In some schools there is a computer in each classroom; in others, laboratories with 20 or 30 terminals accommodate groups for anywhere from 20 minutes to 2 hours per week. A few experimental programs provide a computer for each child in school and another one at home. Some schools have adopted integrated curriculum packages with automated, individualized student monitoring, testing, and reporting, while others have opted for a more eclectic approach that leaves greater autonomy for teachers' planning and implementation. And many classes, of course, use no new technology.

The infusion of computers and development of advanced interactive technologies coincide with

[1] *Mesquite News*, Mesquite, TX, Oct. 28, 1987, p. 10A.

[2] *The Courier Journal*, Louisville, KY, Feb. 19, 1988,

[3] Carolyn Starnes, computer coordinator, Hillview Elementary School, Birmingham, AL, personal communication, Apr. 13, 1988.

[4] The term interactive technologies in education refers to technologies that can respond appropriately and quickly to students or teachers. The interaction can either be between a person and a machine, as in the case of computers, or between people using new forms of communication, as in the case of distance learning. Today's interactive technologies encompass computer technologies, transmission technologies, television technologies, and optical technologies. Much of the discussion in this report focuses on computer-based technologies, because of their impact on schools and because most other key technologies are closely tied to the computer.

troubling news about American schools and have been hailed by many as an important catalyst for reform.[5] Blue ribbon commissions have reported falling test scores and pointed to the growing divergence between our economy's need for highly skilled labor and our schools' capabilities to prepare productive adults.[6] A few visionaries argue that the new technologies alone can solve the difficult problems of America's schools, while those at the other extreme remain unimpressed by claims that technology can improve learning. OTA finds that most educators are cautiously enthusiastic. School personnel and educational researchers believe that interactive technologies have already improved teaching and learning for some children, and they are optimistic about greater improvements that might result from continued development, experimentation, and widespread implementation. There is a general consensus that the appropriate assignment of new technologies within effectively organized schools could make a big difference in academic performance, motivation, and dedication to learning. The broad experimentation of the past decade has generated a knowledge base for schools and policy makers. The Nation is now poised to decide on the next level of commitment.

At the request of the House Committee on Education and Labor of the U.S. Congress, OTA studied the potential of interactive learning tools for improving the quality of education, and analyzed the technological, economic, and institutional barriers to achieving the technologies' future promise.[7]

OTA finds that, although new interactive technologies cannot alone solve the problems of American education, they have already contributed to important improvements in learning. These tools can play an even greater role in advancing the substance and process of education, both by helping children acquire basic skills and by endowing them with more sophisticated skills so they can acquire and apply knowledge over their lifetimes.

At the current rate of resource allocation, the Nation can expect a continued broad base of experimentation, steady but slow improvement in software, and spotty access to the technology by children. If the Nation wishes to accelerate realization of the potential of the technology, a greater investment will be necessary. Costs of such a shift would be borne by Federal, State, and local governments, and the private sector.

Regardless of the rate of investment in interactive technology and support for it, policy makers should focus their attention on four closely related areas if the technology is to move toward realizing its potential. Each of these areas affects, and is affected by, the others:

- expanding the amount and capability of technology in schools to increase student access;
- providing training and support for teachers;
- encouraging innovation and improvement in educational software; and
- supporting research, development, demonstration, and evaluation, with emphasis on ties between research and the classroom.

OTA concludes that the Federal Government must take an active role if interactive technology is to realize its potential for improving education. National needs for educated citizens and workers, combined with traditional Federal responsibility for equity, are the underpinnings for Federal action. Further, the centrally important aspect of research will be adequately supported only as a national undertaking at the Federal level.

[5]Some experts believe that the information technologies can radically change the performance and structure of the educational system. For further discussion see, U.S. Congress, Office of Technology Assessment, *Technology and the American Economic Transition: Choices for the Future*, OTA-TET-283 (Washington, DC: U.S. Government Printing Office, May 1988), pp. 240-251.

[6]See National Commission on Excellence in Education, *A Nation at Risk* (Washington, DC: U.S. Department of Education, April 1983); Committee for Economic Development, *Investing in Our Children* (Washington, DC: September 1985); National Task Force on Educational Technology, *Transforming American Education: Reducing the Risk to the Nation*, A Report to the Secretary of Education (Washington, DC: April 1986); and Carnegie Forum on Education and the Economy, *A Nation Prepared (New* York, NY: Task Force on Teaching as a Profession, May 1986).

[7]For this comprehensive analysis, OTA analyzed survey data on distribution and access to technology and studied patterns of use; reviewed research literature on evidence of effectiveness; conducted site visits to schools and research centers; interviewed publishers, vendors, researchers, policy makers, administrators, teachers, and students; developed case studies; surveyed State technology directors; and convened experts for OTA workshops on educational software development and economics, teachers and technology, research and development of educational technology, and cost-effectiveness issues. In the first phase of the project, OTA prepared a staff paper, "Trends and Status of Computers in Schools: Use in Chapter 1 Programs and Use With Limited English Proficient Students," March 1987.

Federal programs must be flexible and should not constrain the use of technology. Schools' experience with interactive technology, and recent research on how children learn when they use computers, make clear that there is no single "best use" of technology in schools to improve learning. Ideally, Federal programs would encourage continued experimentation and sharing of information from those experiences. Federal research efforts should include studies on the educational effectiveness of currently available technology to address traditional goals, as well as studies of innovation that push the boundaries of learning and cognition.

Educational technologies can be powerful tools for change; not as ends in themselves, but as vehicles to extend teaching and learning processes. The task of developing appropriate software, installing sufficient hardware, training teachers for their new role in electronic classrooms, expanding basic research into the science of human learning and cognition, and ensuring equity of access for all learners cannot be accomplished by any one sector of government or industry.

OTA finds that improved use of technology can be accomplished, in large part, through existing Federal programs. In building on current efforts, Congress could target funds within programs as well as increase levels of funding, make administrative changes, and exert leadership at the national level. A more focused effort to substantially expand the use of technology in education and attain more fully integrated applications across the curriculum will probably require new strategies and perhaps new authority.

Photo credit: Education Week

Demands on schooling have increased with the growing numbers of students who are educationally at risk.

THE SPREAD OF TECHNOLOGY IN SCHOOLS

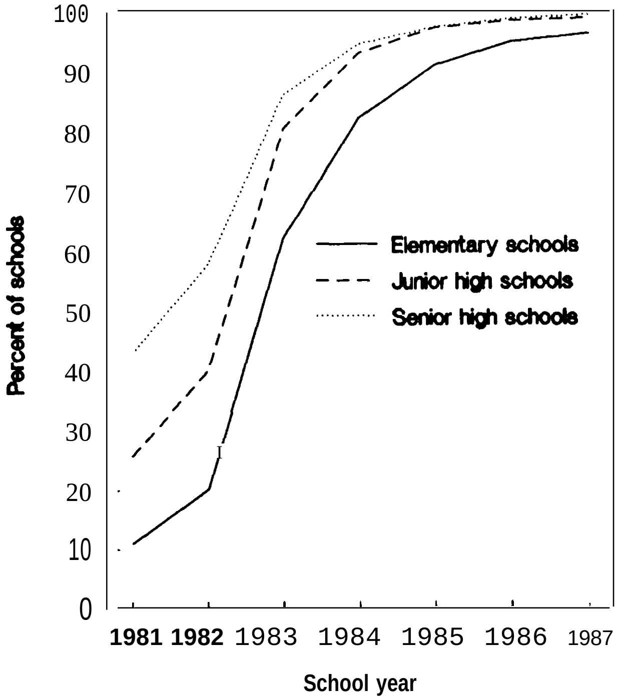
The 1980s witnessed a tremendous expansion in school use of advanced technology of all types. For example, in 1980 very few schools had videocassette recorders (VCRs). Today roughly 90 percent do. VCRs and the availability of cable and satellite transmission have greatly increased flexibility of television use. Television and electronic telecommunications are also being used to deliver instruction to students in remote sites. Such distance learning projects are under way or being planned in 35 States. Recently enacted legislation (Star Schools)[8] will expand these efforts considerably.

Between 1981 and 1987, the percentage of American schools with one or more computers intended for instruction grew from about 18 percent to 95 percent (see figure 1-1). There are now between 1.2 and 1.7 million computers in public schools alone.[9] This is an impressive record of growth and shows a widespread willingness on the part of school districts, schools, teachers, and parents to explore the possibilities of new learning technologies. In a period of less than 10 years, computer-based technologies have been introduced to students with quite different intellectual and behavioral needs, by teachers and administrators of varying backgrounds, experience and technical skill, working in schools with children of diverse demographic, racial, ethnic, and economic composition.

Although computers are widely distributed and access to them by students has increased significantly, the vast majority of schools still do not have enough of them to make the computer a central element of instruction. (See figures 1-2 and 1-3.) The number of computers in U.S. public schools translates to approximately 1 computer for every 30 students. In practice, there is wide disparity—one computer in a classroom, clusters of computers in the library or classrooms, full computer laboratories, and classrooms with no computers. Not all students use computers, and it is estimated that those who do so spend on average a little more than 1 hour per week on the computer, about 4 percent of their instructional time. The National Assessment of Educational Progress[10] report on computer competence found in its 1985-86 survey of 3rd, 7th, and 11th grade students that computers were seldom used in subject areas, but were used almost exclusively to teach about computers.

Furthermore, in analyzing these and other current data available on computer use by different demographic characteristics, OTA found that students in relatively poor elementary or middle schools have significantly less potential access to computers than do their peers in relatively rich schools. Black

Figure 1-1.—U.S. Public Schools With At Least One Computer by Grade Level, 1981-87



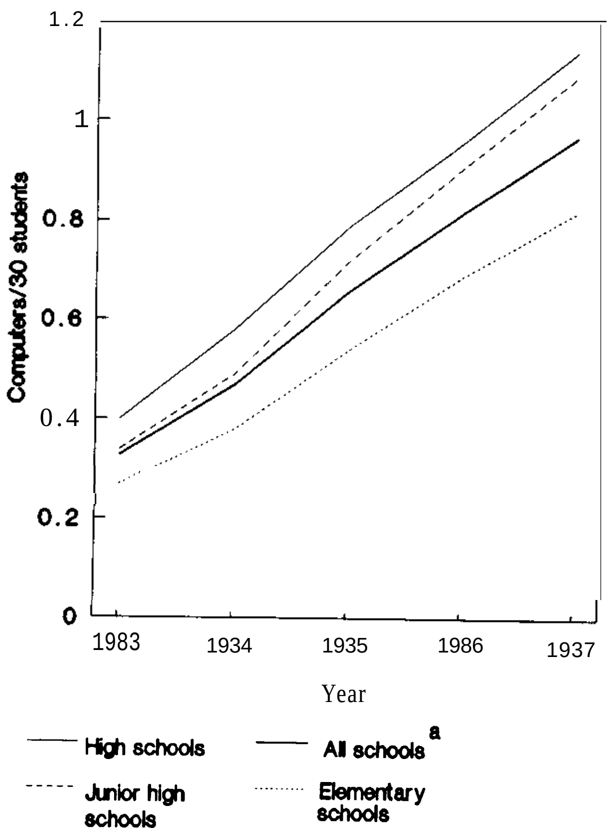
SOURCE: Office of Technology Assessment, based on data from Market Data Retrieval, Inc., 1988.

[8] Authorized under Title II, "Mathematics and Science" of H.R. 5, the Elementary and Secondary School Improvement Act.

[9] Market Data Retrieval, Inc. and Quality Education Data, Inc., the leading market research firms specializing in school technologies, estimate the 1988 total at about 1.2 million. TALMIS, on the other hand, a firm that collects data on the computer industry more broadly, reports a total current base of 2.03 million, of which about 375,000 are in private schools. Finally, T. H.E. *Journal,* a prominent educational technology magazine, reports the highest figure, 2.1 million overall, with 1.7 million in the public schools, based on their recent survey. Variations among these estimates are due largely to differences in sampling methodology and timing of surveys.

[10] Michael E. Martinez and Nancy A. Mead, *Computer Competence: The First National Assessment,* Report No. 17-CC-01 (Princeton, NJ: Educational Testing Service, April 1988).

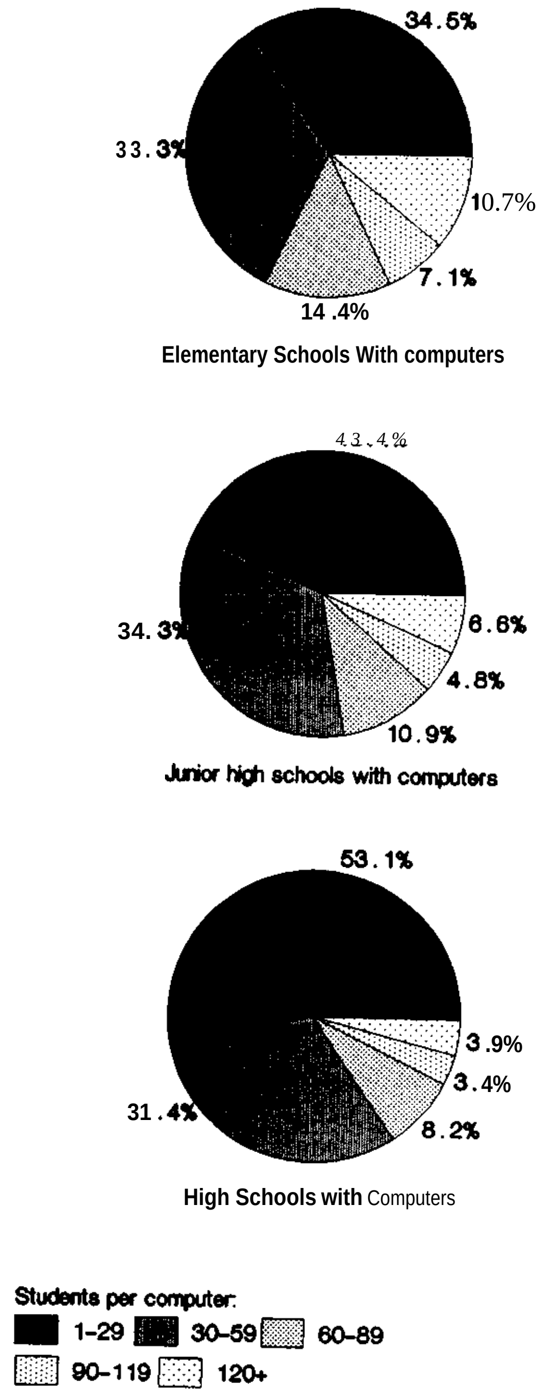
Figure 1.2.—Average Number of Computers Per 30 Students in U.S. Public Schools, 1983-87



[a]Includes K-12 combined schools.

SOURCE: Office of Technology Assessment, based on data from Market Data Retrieval, Inc., 1987.

Figure 1=3.—Distribution of Computers in U.S. Public Schools, 1988



SOURCE: Office of Technology Assessment, based on data from Quality Education Data, Inc., 1988,

students have less access than do whites, particularly at the elementary school level. Limited English proficient students have the lowest access of all. And low-achieving students are more likely to use computers for drill and practice than for problem solving or other activities.[11]

An increase in the amount and capability of technology in schools will be required if the technology is to realize its potential. Expanding the use of technology in the school district, across the State, or throughout the country immediately raises the question of how much it will cost and how it will be financed (see box l-A). Experience over the last decade shows that costs and funding mechanisms vary. In general, Federal, State, district, Parent-

[11]For more detail see, Office of Technology Assessment, op. cit., footnote 7.

Box 1-A.—Educational Technology: What Does It Cost?

A business executive concerned with the efficient allocation of the company's financial resources would condition the purchase of a new computer system on a basic comparison of available models and their costs. Asked by the Board what it will cost to streamline this or that business operation, the executive would be able to report current prices, the predicted lifetime of the equipment (along with a depreciation schedule), and a dollar estimate of expected efficiency gains. Similarly, past expenditures could be scrutinized with respect to alternative technologies that were not chosen and with respect to monetized benefits. Put simply, the measurement of costs and benefits is a routine business function.

Why, then, is it so difficult to get a simple answer to the question "what does educational technology cost?" And why do the numbers appear simultaneously miniscule and gigantic?

Consider, for example, the estimated $2 billion spent on hardware for instructional computing over the last decade. Is that a small amount or a large amount? On average it represents $200 million annually, about $5.00 per student per year, less than two-tenths of one percent of total annual elementary and secondary expenditures (in fiscal year 1986). It is a small amount compared to the amount spent on instructional materials (primarily textbooks), which itself was only about $35 per pupil in 1986, or about 1 percent of total education spending. It is an even smaller fraction of the amount spent on fast food ($50 billion annually) or on pet food ($6 billion annually), and an infinitesimal fraction of gross national product ($4 trillion).

On the other hand, children learn tricks to help them imagine the size of big numbers: at the rate of one count per second, it would take about 31 years to reach a billion! More to the point, the $2 billion spent on school computers in the past decade could have paid 10 years of tuition, room, and board for 20,000 college students, or the home electric and heating fuel bills for 165,000 households, or the medical expenses for 130,000 elderly Americans.

While computer-based learning tools have been adopted enthusiastically—fewer than 5 percent of U.S. public schools now do not have a computer—there are still an average of 30 students to each machine, far too many for the computer to be an integral part of the school day. OTA estimates that the cost of substantially increasing the installed base, and providing a computer for every three children, could increase the Nation's annual expenditures for precollege education by over $4 billion (see table). Again, the relative importance of this expenditure can be dramatized in either direction depending on the desired effect: it is small compared to the overall cost of education, but an enormous chunk of the current instructional materials budget of the Nation's public schools (see figure).

Approximate Cost of Major Expansion of Computers in U.S. Public Schools

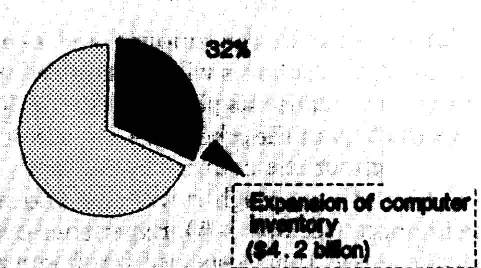
	Cost (in millions)	Annual cost (in millions)
Capital costs for hardware[a]		
12 million computers @ $1,000 each	$12,000	
5 million printers @ $400 each	2,000	
Total	$14,000	
Annualized cost, assuming 6-year equipment life and 10% interest rate		$3,200
Other annual costs		
Software @ $5/student	$200	
Maintenance and upgrades cost	700	
Teacher training[b]	100	
Total (non-capital annual)	$1,000	$1,000
Total estimated annual cost		$4,200

[a]Does not include other peripherals, mass storage devices, or networking.
[b]Assuming 50 percent of all teachers trained annually.

SOURCE: Office of Technology Assessment, 1988.

Estimated Annual Cost of Major Expansion of Installed Base of Computers in U.S. Public Schools (as a Percent of Total Expenditures on Instructional Materials)

Total Instructional Materials Expenditures, 1986-87 ($13 billion)



SOURCE: Office of Technology Assessment based on U.S. Department of Education, National Center for Education Statistics, and Public Elementary and Secondary School Revenues and Current Expenditures for Fiscal Year 1986, March 1988.

The problem, obviously, is that without reference to the ***effects of*** expenditures on educational technologies, the dollar amount is almost meaningless. However, the definition and measurement of educational effects (or outcomes) is extremely complex. Business decisions, such as whether to install a new technology, can usually be assessed for their effect on ***profit,* a** quantifiable indicator of performance. But schools have multiple goals that cannot conveniently be lumped into a single quantitative indicator. The effects of instructional technology (and education in general) take a long time to register and are very difficult to measure. **In addition, there is disagreement about the "production function," or the relationship between specific educational inputs and outcomes. Classroom learning is a complex, dynamic and adaptive process: what a teacher does today may not work tomorrow, what works in New York may not work in Ohio.**

Difficulties in applying conventional productivity analysis to schools, which are familiar to a generation of education economists who have tried, necessitate a cautious approach to cost estimation of educational technology. In particular:

- **Educational technology is a body of tools that can be applied to a wide variety of educational purposes. The question "how much does it cost?" should be recast with reference** to specific technologies.
- **Because classroom learning is a complex, interactive process subject to many stimuli, it should be viewed as a living experiment. Under ideal conditions, teachers and their students continually learn about learning and adjust to their changing environment. The computer, or any educational tool, cannot be introduced into such an environment** with the expectation of immediate benefit. Time is needed to integrate it in a useful way. The costs of new learning tools, then, include much more than the easily quantifiable market prices for hardware and software.
- The useful life of a classroom computer, an important element in cost estimation, depends on many factors: ruggedness or physical durability of the equipment, capacity to handle new and more sophisticated software, and changes in teachers' classroom methods. In addition, schools cannot typically sell or trade-in **used equipment,** nor do they simply discard machines that **have become obsolete. Thus, the establishment of an appropriate replacement cycle, which is relatively easy** for books {usually 5 **to 6 years), becomes a more complicated matter in the case of computer equipment.**
- **Increasing the utilization of school computer equipment can raise costs: for example, making the equipment accessible to evening school programs or to local libraries entails added person**nel, **maintenance, and security expenses. However, increased utilization can improve the overall efficiency of the installed equipment by creating additional revenues that offset operating expenses.**

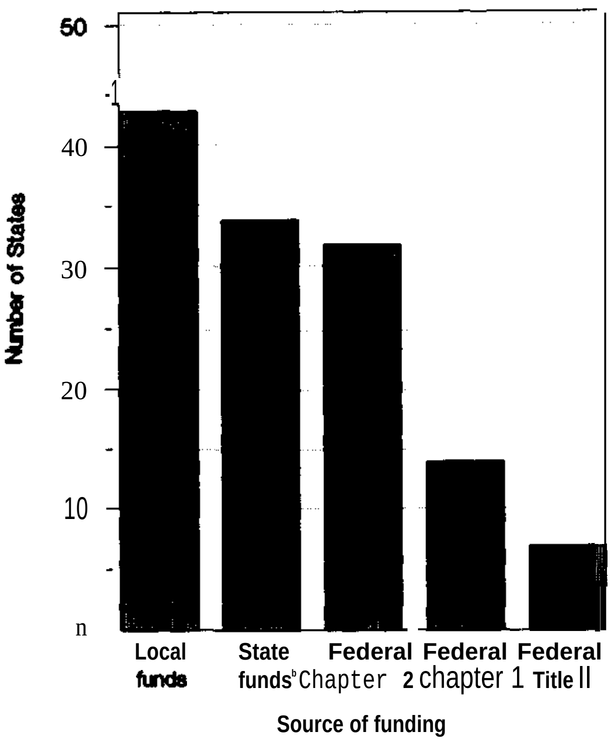
Teacher Association, or business contributions, or a combination of these support technology used by school districts. (See figure 1-4.) Costs include purchases of technology, teacher training, maintenance, continuing upgrades of hardware and software, and supporting personnel.[12] (See table l-l.)

OTA finds that States are key players in improving the use of technology in education, although the level of support across the States is by no means uniform. In addition to helping schools acquire technology, States provide funding, technical assistance, and other resources for improving the use of technology in schools. Their role has changed rapidly. In 1981, only a few States were involved with computers.[13] By 1987, almost every State had created an administrative position or department to plan, implement, or monitor State educational technology programs. Some States have established technology skill requirements for teachers and guidelines for technology-related curricula, and many are involved in some aspect of teacher training, software evaluation, or information dissemination. A few have produced instructional software or distributed software electronically, Some have funded demonstrations of new uses of technology such as distance learning. In identifying barriers to increased use of technology, almost

[12] Sheila Cory, coordinator of program evaluation and educational computing, Chapel Hill-Carrboro City Schools, NC, personal communication, March 1988.

[13] The States of Alaska and Minnesota were early leaders. See, U.S. Congress, Office of Technology Assessment, *Informational Technology and Its Impact on American Education,* OTA-CIT-187 (Washington, DC: U.S. Government Printing Office, November 1982), pp. 214-220 and 227-232.

Figure 1-4.—State Estimates of Major Sources of Funding for Technology Used by School Districts[a]



[a]State technology coordinators were asked to select the top three sources of funding used by districts.
[b]State funds used for technology by districts Include: 1) funds for technology allocated to all districts; 2) grants for technology; and 3) grants that may be used for technology.

SOURCE: Office of Technology Assessment, State Educational Technology Survey, 1987.

two-thirds of the States surveyed by OTA cited lack of funds as a serious problem.[14]

Federal programs have been and continue to be another important resource, particularly in increasing access to computers by educationally disadvantaged students, and in enabling districts to purchase hardware and software. Compensatory Education Programs (Chapter 1[15]) in every State fund the purchase and/or lease of computer hardware and software for use with educationally disadvantaged students,[16] and almost three-fifths (58 percent) of Chapter 1 teachers in public schools report that they use computers to teach their students.[17] In all districts, the Federal Block Grants (Chapter 2) can be used to purchase hardware and software.[18] Most recently, in an OTA survey, 34 States ranked Chapter 2 as one of the top three sources for funding technology at the district level.[19] Other Federal programs support acquisition of computer hardware and software, but the amounts spent on technology purchases do not appear as separate items in their budgets and therefore cannot be measured. These programs include the "Math/Science Program" (Title II of the Education for Economic Security Act, EESA), the Magnet Schools Assistance Program (Title VII of EESA), Vocational Education (The Perkins Act), and the Education for the Handicapped Act.

National needs for educated citizens and workers combined with issues of equity suggest that the Federal Government work with State, local, and private sector efforts to expand the use of interactive technologies in schools. This could include increased funding and clear direction from Washington, supporting the role of technology as one component of improving learning.

Steady funding is vastly preferable to money that must be spent quickly. This is because local districts and States need time to plan for integrated uses of technology and to train personnel. Flexibility is also important, as districts and States need freedom to revise these plans as the technologies change and as the learning potential they offer evolves. Moreover, efforts that build on local, State, and private sector experience and resources could provide greater leverage of Federal funds.

[14]OTA State Educational Technology Survey, 1987.

[15]Chapter l of the Education Consolidation and Improvement Act.

[16]OTA Survey of State Chapter 1 coordinators, see office of Technology Assessment, op. cit., footnote 7.

[17]OTA's analysis was based on original data from the 1986 National Survey of the Education Consolidation and Improvement Act Chapter 1 Schools conducted by Westat Corp. for the U.S. Department of Education's 1986 National Assessment of Chapter 1. See Office of Technology Assessment, op. cit., footnote 7, p. 50.

[18]Chapter 2 of the Education Consolidation and Improvement Act distributes these block grants to States based on the student population figures. Eighty percent of the funds a State receives must go directly to local districts, again according to a formula based on the number of school-aged children in the district. A 1986 study found that support for computer-related activities accounted for 30 percent of all local Chapter 2 expenditures. SRI International and Policy Studies Associates, "The Educational Block Grant at the Local Level: The Implementation of Chapter 2 of the Education Consolidation and Improvement Act in Districts and Schools," prepared for the U.S. Department of Education, January 1986.

[19]OTA State Educational Technology Survey, 1987.

Table 1-1.–Costs of Computer Use (Frank Porter Graham Elementary School Chapel Hill, North Carolina, 1986-88)

	Hardware[a]	Software[b]	Supplies[c]	Staff development[d]	Personnel[e]	Repairs/ maintenance
1986-87						
Federal						
Chapter 2	$ 373	—	—	—	—	—
Title II	—	—	—	$ 608	—	—
State	4,195	$ 556	—	454	—	—
Local						
Current expense	—	—	—	441	$1,300	$1,254
Capital outlay	—	—	—	—	—	—
School						
PTA	—	1,024	476	—	1,915	—
Total	$ 4,568	$1,580	$ 476	$1,503	$3,215	$1,254
1987-88						
Federal						
Chapter 2	$ 373	—	—	—	—	—
Title II	—	—	—	$ 608	—	—
State	—	—	—	—	—	—
Local						
Current expense	1,000	$ 611	$ 611	300	$1,550	$1,290
Capital outlay	1,111	—	—	—	—	—
School						
PTA	3,164	1,000	460	—	2,708	—
Total	$ 5,648	$1,611	$1,071	$908	$4,258	$1,290
Total 2 years	$10,216	$3,191	$1,547	$2,411	$7,473	$2,544

[a]**Hardware:** Computer hardware currently consists of 24 Apple II computer stations. Fourteen are grouped together in a computer laboratory and 10 are located in individual classrooms, the science laboratory, or the media center.

[b]**Software:** Software includes programs provided by the school district to support the district-developed curriculum, Additional software has been purchased by the school to support the school and teacher objectives.

[c]**Supplies:** Supplies needed t. support the district-developed curriculum are provided by the district, These include such things as books and discs. Additional supplies, such as paper and ribbons, are funded by the school.

[d]**Staff development:** District-level workshops are designed to support the district-developed curriculum. Attendance is required at these Sessions. Optional Staff development is also provided by both the district and the school,

[e]**Personnel:** On-site personnel with direct responsibility to the computer education program consists of a part-time computer laboratory aide funded by the PTA. Additional personnel resources are provided by the district through their funding of a half-time coordinator who serves nine schools,

SOURCE: Chapel Hill-Carrboro Public Schools, Chapel Hill, NC.

Congress can profit from the States' leadership and expertise in advancing the use of technology. There is much that could be learned from various State efforts in teacher training, software evaluation and development, and model projects and demonstration efforts described throughout this report. Federal funds could expand State, local, and private sector efforts. Federal assistance through conferences or through electronic networks could facilitate sharing information.

WHAT THE TECHNOLOGY CAN DO

One of the most obvious questions about using interactive technologies in schools is "Does it work?" Performance and productivity are difficult to measure precisely, in part because the near-term effects of educational technologies may be different from what these technologies might eventually achieve.

OTA examined recent research on educational uses of computers in a wide range of applications in many different settings. Although the results build an incomplete and somewhat impressionistic picture, they do suggest that certain configurations of hardware and software, used with particular populations of children and under the supervision of competent teachers, contribute to meeting specific *instructional* objectives. OTA finds that the varied capabilities of the technologies are key to their power. Educators use interactive technologies for many purposes; there is no single best use. The following are among the most promising current uses and demonstrations.

Drill and practice to master basic skills.–For almost **30 years, computers have been used** to provide instruction or drill and practice in basic skills such as mathematics and reading. Computer-assisted instruction (CAI) has proven to be an effective supplement to traditional classroom instruction. For example, one recent study showed that elementary school children who used CAI for mathematics gained the equivalent of 1 to 8 months instruction over peers who received only traditional instruction.

Development of writing skills.—Although word processing by itself does not create better writers, it has helped ease the physical burden of writing and revising. Studies have shown that both mainstream and special students who used the word processor as a supplement to writing instruction have made significant gains in writing ability. In addition, word processing technology has stimulated research on the most efficient ways to teach students to read, critique, and revise their written work. The findings of this research are being incorporated into new software.

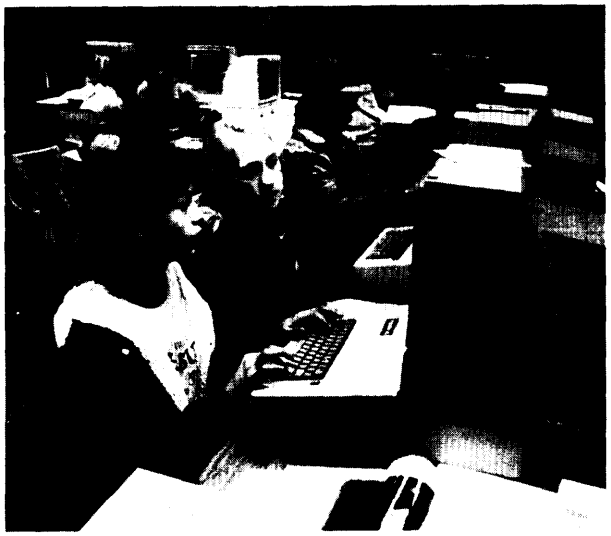


Photo credit: **BreadNet Project**

English teacher Linda Henry and ninth grader John Quick Bear are part of the electronic network of rural schools set up by the Bread Loaf School of English at Middlebury College. This classroom on the Oglala Lakota (Sioux) reservation in Kyle, South Dakota, is one of 50 in a project to see if computers and telecomputing can improve the teaching of writing.

Problem solving.-–Problem solving skills and "higher order" thinking have always been difficult to teach. There is some evidence that teachers can use computer simulations, educational games, databases, and other software to train students to break down problems into their component parts and set strategies for their solution. More research is needed to understand problem solving strategies used by learners in different contexts and curriculum areas.

Understanding abstract mathematics and science concepts.—One of the more promising uses of computers is as a tool in the science laboratory. Microcomputer-based laboratories (MBLs) combine microcomputers with probes to measure phenomena such as light, heat, and temperature. With specially designed software, students can produce almost instant graphs of the data and explore effects of different variables. Studies indicate that students using MBLs have a deeper understanding of complex scientific concepts than do students not using MBLs. The computer is an invaluable tool for teaching graphing concepts. Computer simulations have also proved an effective way of helping students visualize abstract concepts. (See box 1-B.)

Simulation in science, mathematics, and social studies. -Simulations provide science students with self-contained worlds—for example, a frictionless world where the laws of Newtonian physics are more apparent—in which they can experiment and quickly see the result. Students can test abstract concepts and experiment with scientific processes that are not feasible or are too dangerous for actual classroom work. Simulations are also effective tools in social science. By playing the role of world leaders or citizens in other countries, for example, students have been motivated to engage in high level critical thinking, gain a better understanding of political affairs, and appreciate different perspectives on issues.

Manipulation of data.–Database management systems have become very popular in classrooms. These encourage students to define a problem in specific terms and break it up into its component parts. Students must then identify the data needed, extract them from the database, put the data in a useful order, use the data, and then communicate findings to others. Limited research results suggest that students using databases outperform other students

Box 1-B.—The Teacher As a **Coach: Teaching Science With a Microcomputer-Based Laboratory**[1]

Douglas Kirkpatrick teaches an eighth grade physical science class in Walnut Creek, California. Working with a research team from the nearby Lawrence Hall of Science, he has been using the computer as a "silent laboratory partner," helping his students understand concepts in heat and light in a new way. His 32 students are teamed up in pairs using 16 microcomputers donated by Apple. The software is made up of microcomputer-based laboratory (MBL) materials, temperature probes, light probes, and heat pulsars for the collection of data, with accompanying curriculum materials, all developed by the Technical Education Research Centers in Boston.

Kirkpatrick found that his students had reasonable intuitions about the effect of insulation on the temperature of a liquid—gained from their prior experience with styrofoam cups—and the relationship between volume of a liquid and the amount of heat that needs to be added to make it boil-gained from heating large and small quantities of liquid in the kitchen. However, Kirkpatrick's students, like other science students, had persistent misconceptions about other scientific phenomena. As he noted, many students believed "you only have a temperature if you are sick," or "you have more hot chocolate, so yours is hotter than mine," or "temperature is all the degrees, but heat only refers to temperatures that are above warm." Merely telling students how heat differs from temperature or having them read about it in a textbook has traditionally had little or no effect on these entrenched misconceptions.

In the past, Kirkpatrick had clustered his students in small groups in a laboratory to study temperature. He had them observe water and moth flakes cooling, with some students calling out times and temperatures while others painstakingly recorded the data. Later, teams constructed graphs of their efforts and attempted to relate the **curves on the graphs to key moments in the experiments. While students typically found these laboratory experiments more interesting and fun than a lecture or reading about temperature, the underlying cognitive concepts still did not seem to take hold.**

Doing the experiment with the MBLs, Kirkpatrick's students were freed from the tedious mechanics of data collection, enabling them to focus on changes occurring before their eyes as recorded on the computer. Having the computer simplified experiments that would otherwise have been confusing. Real-time computer graphing was an antidote to their typically limited adolescent attention spans. His young experimenters, like "real" scientists, were able to use technological tools to collect, display, and analyze data, freeing them to concentrate on the effect of the experimental action, to observe, discuss, and analyze. Students were able to repeat their experiments easily when they had questions. They could also readily compare results with their fellow students, giving rise to lively class discussions about the meaning of the experiments.

If the computer was the silent laboratory partner, what was the teacher's role? Like any laboratory situation, where students have a hands-on engagement with learning, the teacher became a coach. In this instance, Kirkpatrick found that most students at first completely trusted the data from the computer. It was Kirkpatrick's job to direct their attention, to help them become aware of sources of invalid data, to teach them to diagnose the causes and help them evaluate data the computer collected. He taught them to detect poorly calibrated probes, discard data from such probes, and to recalibrate their scientific instruments. He guided their discussion to confirm their understandings.

Kirkpatrick has been delighted by the interactions he has observed among the students, and presides over countless fascinating classroom discussions of complex science **concepts,** He **says, "I can't imagine a physical science laboratory without computers anymore."**

[1]This is a nonfiction account of the activities carried out by a real classroom teacher. See also Marcia C. Linn, University of California at Berkeley, "Using the Computer as a Laboratory Partner: Cognitive Consequences," paper prepared for the symposium on "Computers in School: Cognitive and Social Processes" at the Second EARLI Conference, Tubingen, Germany, September 1987.

in tests of information processing skills. In addition, teachers report that students using databases understand underlying concepts and relationships better, work more cooperatively, and become more enthusiastic about gathering and analyzing data.

Acquisition of computer skills for general purposes, and for business and vocational training.— The most obvious use of computers and related tools in the classroom is to prepare students for the increasingly technological world they will face when they leave school. Keyboarding and skill in using generic computer programs are replacing the early focus on programming for all students. Advocates of teaching programming to students argue that it is an important skill that can improve problem solving abilities and has wide applicability to many areas of the curriculum, but research on the cognitive consequences of programming has produced mixed results.

Access and communication for traditionally unserved populations of students. -perhaps the most impressive applications of computer-based technologies are in the field of special education. Some teachers have described the computer as "the freedom machine" because it has made communication itself possible for their students. Word processors allow students who could not hold a pencil to write (see box l-C); speech synthesizers provide some students with a means to communicate orally for the first time.

Access and communication for teachers and students in remote locations.—Television via satellite brings classes in foreign language, calculus, and many other subjects to schools that cannot provide them because of the small numbers of students or because of the absence of specialized teachers. Declining costs of hardware and increased accessibility of telecommunications technology make distance learning projects more feasible and efforts are expected to increase.

In addition, electronic networks allow students and teachers to share information and experience across cities, States, or continents, thus ending the isolation of the classroom. Several projects in science and writing using electronic networks have been particularly promising.

individualized learning.–The computer is interactive; a student's entry generates immediate feedback. The increasing capacity of computer-based technology makes it possible to develop instruction that adjusts to each student's prior knowledge, rate of learning, and the nature and style of the student's response. For example, technology offers some very promising applications for strengthening reading comprehension through analysis of the student's understanding of the text; intelligent tutoring systems in areas such as geometry can provide the learner with an expert and sensitive tutor; and "hypertext"

Photo credit: Michael **Zide,** Smith College

For children like Mallory Sanderson and Matthew Jenkins at the Clarke School for the Deaf, computers have opened new doors for learning.

systems can allow students to manipulate text, graphics, and different levels of information. The computer can also keep exact records of student progress, which helps the teacher determine individual student needs.

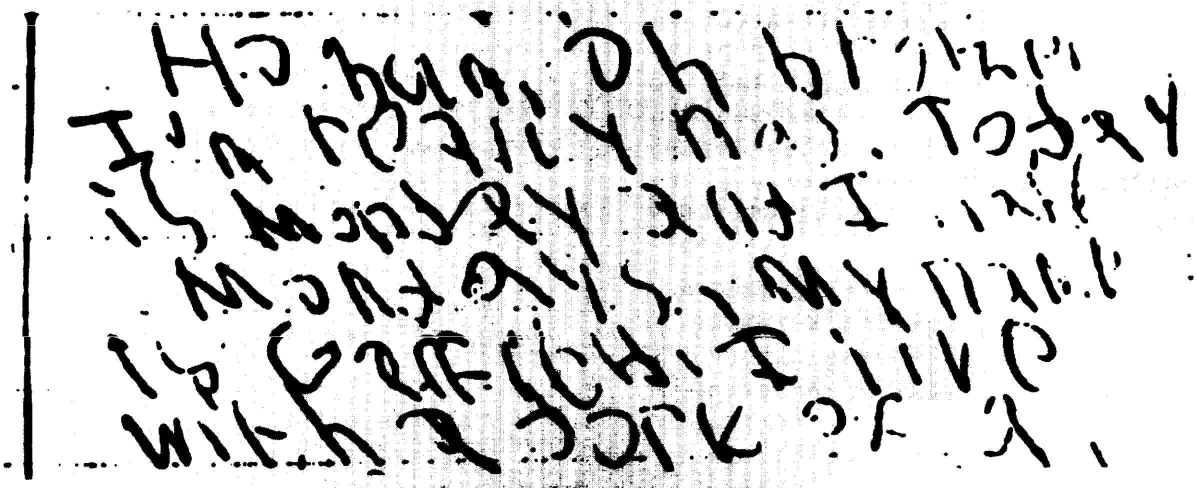
Cooperative learning.–The new technologies can encourage cooperative learning. Telecommunications technology, by definition, makes new forms of communication and cooperation possible. On an electronic network, students from many locations can gather information from many sources. Teachers are especially enthusiastic about the ways computer simulations and problem solving software encourage cooperative learning in the classroom. Students of mixed abilities can be grouped in small or large teams to wrestle with tasks that cannot be performed individually.

Management of classroom activities and record. keeping.–Teachers believe that technology eases some aspects of classroom management. There are reports that students engrossed in computers pose fewer discipline and absenteeism problems. Computer programs such as spreadsheets, database managers, and desktop publishing can streamline recordkeeping and material preparation. In addition, computers make it easier to record the progress and determine the needs of individual students. As pressures for accountability rise, more testing and recordkeeping are likely, even if they do not necessarily contribute to the learning process itself.

Clearly the technology serves many functions well. **Emphasizing a single use of technology now could**

Box 1-C.—Writing By Hand/Writing With a Word Processor[1]

Jami is a youngster with some motor involvement who was in our writing group. At school he was required to write all of his homework. He was required to write his spelling words 10 times each by hand. This literally took hours. The example below is a sample taken from his final version of a paper he handed in on Garfield.



Through the Daedalus Project we provided Jami with a computer, instruction on keyboarding, word processing, and writing skills following the Daedalus Writing Curriculum. What follows is an article Jami wrote for the *Daedalus Newsletter* during a retreat in March, 1987.

Wrestlemania III, March 29, 1987
BE THERE!!!!

On March 29, 1987, in the Pontiac Silver dome in Michigan, there will be 90,000 screaming fans suffering from Hulkamania!!!! The feature match will be between Hulk Hogan and the 8th Wonder of the World: Andre the Giant. Andre the Giant is undefeated in his professional career which has lasted for 15 years. Hulk Hogan, on the other hand, has been the champion of the WWF for the past three years. It should be a darn good match between the 7 '4", 507 pound giant, and the 6 '8", 325 pound Hulkster. You can be sure that Hulkamania will be running wild!!!!! Be there or be crushed!!!!!

Jami can now complete his spelling assignments in 20 minutes. Jami is our first published author; he has an article and a poem coming out in an upcoming JAYCEEs magazine.

[1]The following text is excerpted from *ConnSENSE Bulletin: Connecticut's Special Education Network for Software Evaluation*, vol. 5, No. 1, October 1987, University of Connecticut, Storrs, CT.

stifle much needed innovation, initiative, and experimentation. As researchers and practitioners gain experience with current technology, they are discovering new educational uses and are raising additional questions about the learning process. **OTA concludes that Federal programs should not constrain technology, but should allow, perhaps encourage, flexibility of use by different districts.** Many districts argue that existing Federal regulations hamper their flexibility to move hardware and personnel according to their changing needs, or to increase the productivity of equipment through multiple uses.

The need for studies evaluating different approaches continues.—Research has covered some areas more than others, and missed some areas entirely. For example, there has been some research on the cost-effectiveness of traditional CAI, finding it appropriate under specific conditions. But effectiveness assessments of newer applications of technology are needed, as are longitudinal studies that follow groups of users over time. This kind of school-based research is difficult and costly. Better data and sophisticated tools are needed to measure cost-effectiveness, and it is difficult to gather detailed administrative data, apply economic considerations, measure effects, and account for social and institutional variables. Most school districts and States do not have resources to conduct such research and evaluation. **Federal research should include studies on both the educational effectiveness and cost-effectiveness of currently available technologies addressing traditional goals, and studies of innovations that push the boundaries of learning and cognition.**

- **Congress may wish to encourage evaluation and research on the uses of computers in education through existing Federal programs,** possibly by including requirements for formal evaluation in National Science Foundation (NSF) technology projects, or requiring that the effectiveness of technology in meeting program goals be measured in major studies, such as the $10 million comprehensive Chapter 1 evaluation study authorized by Congress to be conducted by the Department of Education.
- Other initiatives that could provide data are the $30 million "Improvement Fund" aimed at improving the performance of students and teachers, the Secretary's Fund for Innovation, the Star Schools Program, and special education, bilingual education, and adult literacy programs. The Federal Government could provide assistance in data collection, research design, and dissemination of results.

TEACHERS AND TECHNOLOGY

Educational technologies are not self-implementing, and they do not replace the teacher. **OTA finds that investments in technology cannot be fully effective unless teachers receive training and support.** OTA has found many powerful examples of creative teachers using computers and other learning technologies to enhance and enrich their teaching. But this does not occur unless four interrelated conditions are met: training in the skills needed to work with technology, education that provides vision and understanding of state-of-the-art developments and applications, support for experimentation and innovation, and—perhaps most valuable of all—time for learning and practice.

Recent studies show that most teachers want to use the newest tools of their trade and to prepare their students for the world of technology outside the schoolroom. But despite the presence of computers in almost all American public schools, only half of the Nation's teachers report having ever used computers. The number who use computers regularly is much smaller. Barriers to greater use include lack of equipment, inadequate or inappropriate training, and, for some, anxiety about new technology.

How Teachers Use Technology

Asking how teachers use computers and what effects computers have on teaching are questions almost as broad as "How do teachers use books and how do books affect teaching?" To no one's surprise, OTA finds that teachers' use of computers depends on their instructional goals, teaching approach, training, the software and hardware available to them, and the instructional setting. Some teachers use computer laboratories; some have units in their classroom. Some use the computer to teach lessons to the whole class; some emphasize individual instruction. Some tie the computer tightly to their standard curriculum; some create a whole new curriculum. In general, teachers are moving away from teaching about computers and computer programming and toward integrating the computer into the curriculum.

One of the most significant impacts of computers has been on teaching style. **Teachers can function as facilitators of student learning, rather than in their traditional role as presenters of ready-made information. Because computers allow students to** work on problems individually or in small groups while the teacher circulates among them, some teachers find they are able to see more of the learning process. The interactive nature of computers lets students work at their own speed, figure things out for themselves, and learn from each other. Teachers can be coaches and facilitators as well as lecturers.

Given the right circumstances, teachers could choose the appropriate way to reach their students. With the computer and other tools, the range of opportunities increases. But teachers have to be allowed to choose, willing to make choices, and qualified to implement their choices effectively. **OTA finds that, just as there is no one best use of technology, there is no one best way of teaching with technology.** Flexibility should be encouraged, allowing teachers to develop their personal teaching approach utilizing the variety of options offered by technology.

To be sure, not all teachers are enthusiastic about the computer. Some report that it has caused little or no change in their teaching style or content. Interestingly, these reactions often come in situations where teachers are frustrated by insufficient hardware or software, or when they have not received training or had opportunities to develop confidence in using computer tools.

OTA finds that teachers who have taught with computers agree that—at least initially—most uses of computers make teaching more challenging. Individualizing lessons, matching software to curriculum, scheduling student computer time, monitoring use, providing assistance, and troubleshooting —all add burdens to the teacher's time. While the computer can minimize some administrative chores and ease classroom discipline problems, the net effect is increased demand on teachers' time and creativity. Many teachers seem willing to trade off this increased time for more excitement in the classroom and new opportunities to expand their horizons. OTA finds that very few teachers have adequate time for planning and preparing to use technology, Federal, State, and local policy makers should be aware of the need for teachers to study on their own or in formal courses, to attend conferences and professional meetings, and to gain comfort with the technology and find applications for the classroom.

Teacher Training in Technology

A major aspect of the current drive to improve American education is the focus on raising professional teaching standards and giving teachers greater responsibility and autonomy. Technology, while not yet central in these efforts, could be an important

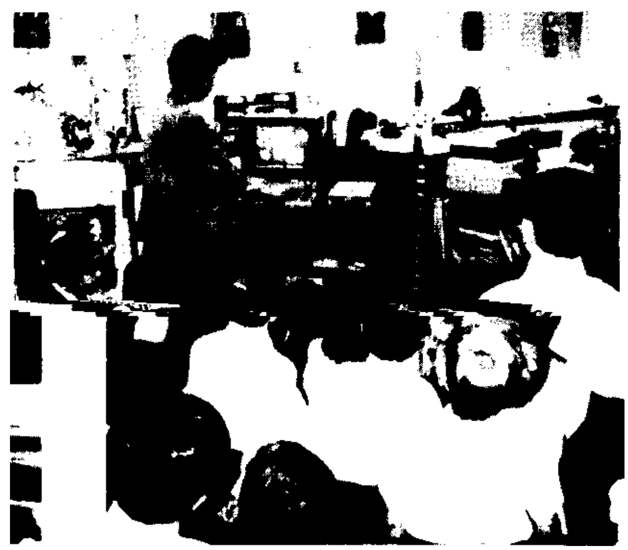


Photo credit: *Computer Learning Month*

Teachers find different ways to use computers in their classrooms: with small groups and with their entire class.

lever for change. **But the vast majority of those now teaching or planning to teach have had little or no computer education or training. The most recent data available indicate that only one-third of all K-12 teachers have had as much as** 10 **hours of computer training.**[20] **And much of this training focused on learning** *about* computers, not learning how to teach *with* computers.

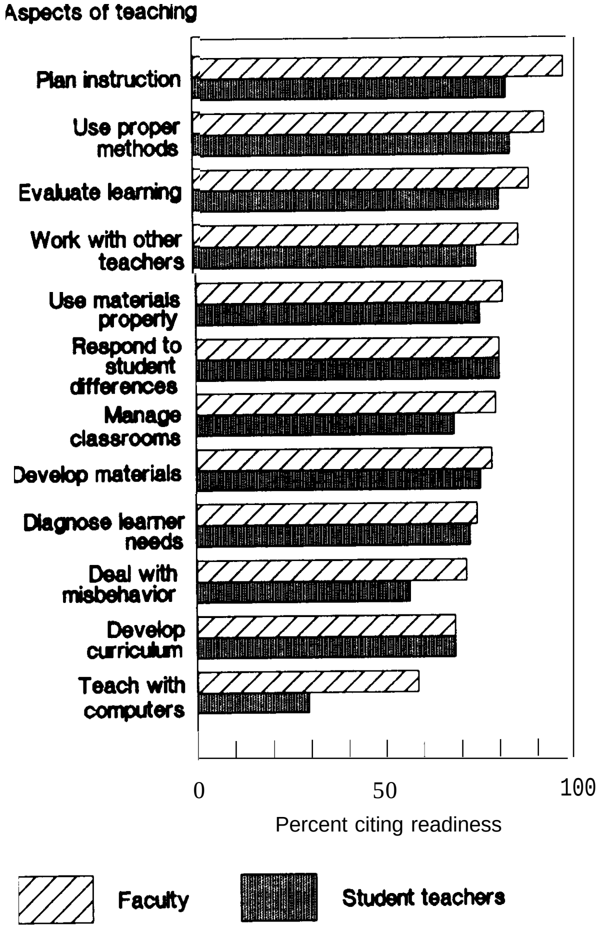
The situation is no more promising for those just entering teaching. A recent national survey of education majors indicated that less than one-third (29 percent) perceived themselves to be prepared to teach with computers.[21] (See figure 1-5.) Although almost all teacher education programs provide some computer training for teacher candidates, many of these programs do not have adequate resources (up-to-date equipment and faculty with expertise in technology) to go beyond the basic introductory computer courses. They are also constrained by State-mandated reforms that define and often restrict the teacher education curriculum. **Despite a nationwide call to improve teaching, there is almost no Federal money for the training of new teachers. Congress may wish to upgrade the training of teachers overall, making understanding of technology an integral part of their preparation, through various options targeted to both students and teacher education institutions:**

- Grants and loans (forgivable or low-interest) for students entering teacher-training programs.
- Funding to schools of education to support purchase of equipment so they can have more current technologies available in their teacher training programs.
- Grants to support workshops and courses to upgrade the technology skills of education school faculty so that the education program reflects changing philosophies and so that methods courses demonstrate the application of technology across the curriculum.
- Demonstration grants for innovative teaching internships where electronic networks connect the student teacher to the education school.
- Grants for research on methods of training teachers to use technology and funding for the dissemination of promising practices.

[20] Office of Technology Assessment, op. cit., footnote 7.

[21] American Association of Colleges for Teacher Education, *Teaching Teachers: Facts and Figures* (Washington, DC: 1987).

Figure 1-5.—Readiness to Teach: Perceptions of Education School Faculty and Student Teachers



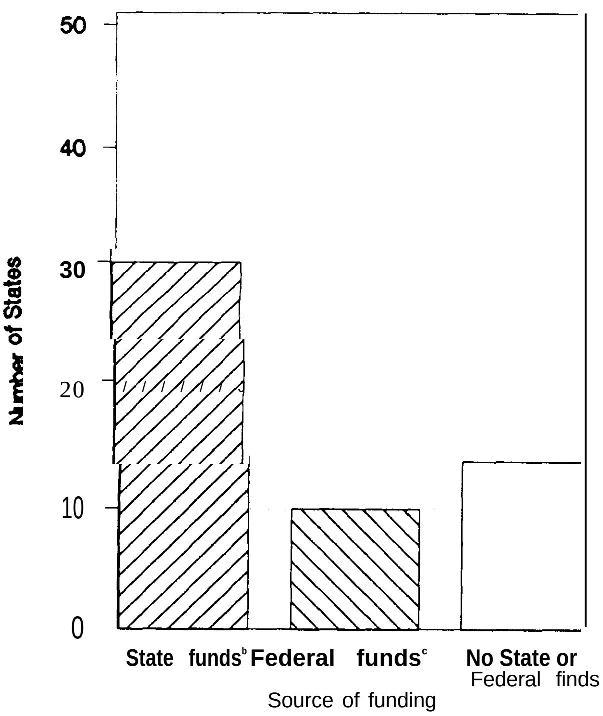
SOURCE: Research About Teacher Education Project, Teaching *Facts and Figures* (Washington, DC: American Association of Colleges for Teacher Education, 1967).

OTA finds that although preservice education is important, it serves only as a first step; training and the environment of support is even more critical once teachers are in the classroom. Teachers will need continuing inservice programs as technology changes, as more effective uses of technology are developed, and as research provides a better **understanding of how children learn.**

Inservice training in technology has unique requirements that distinguish it from traditional inservice activities. Most obviously, teachers need a well-equipped facility and an environment that allows them to explore and master the technology. In addition, inservice training in technology must often overcome the experienced teacher's varying levels of "technology anxiety." Instructors for these activities must appreciate teachers' special concerns regarding computers. Moreover, studies point to the critical importance of followup and continuing assistance.

Federal support has contributed to the inservice technology training of teachers, through NSF's Teacher Enhancement Program and various Department of Education programs (Chapter 2, Title II, Special Education, Title VII, Vocational Education). States have been major supporters as well (see figure 1-6 and box l-D). The primary responsibility for continued professional development of teachers, however, lies with the local district. The amount of money the Nation's 16,000 school districts have spent on inservice technology training is currently impossible to track. What is clear is that many districts have very limited funds available for inservice training in general; many also have limited facilities, resources, and expertise to prepare teachers to use technology. Some districts have developed working arrangements with other districts, nearby universi-

Figure 1-6.—State Estimates of Sources of Funding for Inservice Technology Training[a]



[a]State technology coordinators were asked to select the top three sources of funding for technology at the local level.
[b]State funds include: 1) funds for technology training; 2) professional development funds or grants; 3) funds that flow through regional centers or districts; and 4) general State aid used at local discretion.
[c]Federal funding includes Title II Chapter 1, Chapter 2, and Special Education funds.

SOURCE: Office of Technology Assessment, State Educational Technology Survey, 1987.

Box 1-D.—New Hampshire's Computers for Teachers Program[1]

The State of New Hampshire is taking an innovative approach to developing teachers' confidence and competence in using computers. As a part of the Governor's Initiative for Excellence in Education, $2.5 million in State monies has funded the purchase of computers for teachers. The computers are not intended to be kept locked up in the schools, but are for the teachers' personal use, whether at home or at school or both. When teachers apply for a computer, they are also provided with support and materials—training, software, and maintenance.

There is no cost for the teacher to participate, but the districts provide matching funds. Two-thirds of the districts have participated, contributing an additional $1.25 million to the Computers for Teachers Project. Overall 1,950 of the State's teachers have received a computer to take home and completed initial training.

During the summer of 1988, 130 of the teachers with computers will attend a 2-week advanced training course. The State hopes that these teachers will become trainers of other teachers in their home districts, forming an active resource network to extend the impact of the available training funds ($75,000).

Another aspect of the Governor's Initiative is the Technology in the Classroom project, which funded 62 demonstration projects supporting creative ways of using the computer in the classroom. Thirty-eight projects involve videodisc applications. State officials estimate that these demonstration projects have influenced some 2,000 teachers in schools across the State. Taken together, these efforts intend to involve a critical mass of teachers who become comfortable in using computers to extend their own productivity, and can experiment with and discover ways to use technology in their classrooms.

[1]OTA State Educational Technology Survey, 1987. For more information, contact Governor's Steering Committee for Excellence in Education, Concord NH.

ties, regional service centers, and combinations of these to expand their own capacity and expertise.

Enhancing the resources of schools of education to provide technology education programs for entry-level teachers would also improve inservice programs, as these schools often train working teachers.

- **Congress may wish to expand current Federal activities for inservice teacher training in technology.** The NSF Summer Institutes for teachers are well regarded and could be expanded to include broader applications of technology in interdisciplinary areas. The Department of Education programs that include provisions for teacher training (e.g., Title II, Chapter 1, Special Education, Bilingual Education) could be strengthened with greater resources targeted to inservice computer education. The Federal Regional Education Laboratories could be used to provide training for teachers. The National Diffusion Network, designed to share results of innovative and effective programs, could validate teacher training activities and provide greater dissemination of effective practices.

Interactive technologies offer new possibilities for supporting teachers as they work. Teachers in several experimental writing and science projects use electronic networking to exchange information, develop lessons, and ask for help from their colleagues and project coordinators. Many find that networking is very convenient and efficient. Schools, State agencies, and regional centers are also beginning to make use of the communications capabilities of computers, using modems for networking activities such as electronic mail, information sharing, computer conferencing, and subject-oriented forums. Such networks have the potential to help overcome one of the most basic problems of the classroom teacher —isolation. (See box l-E.)

- **Congress may wish to encourage computer networking as an informal source of teacher support.** This can be accomplished through existing programs, such as the Special Education Resource Network sponsored by the Office of Special Education, NSF's support for the electronic network linking State science supervisors, or through demonstration grants funded under the Secretary's Discretionary Program. Federal efforts could provide initial or partial support for State, regional, or national networks that could link teachers and subject matter specialists or administrators. Some educators have begun to discuss the development of a nationwide, government-financed public school telecommunications network similar to those already functioning in government-sponsored civilian and defense research. Congress may wish to study further the question of network access and telecommunications charges, and whether these issues seriously inhibit teacher use of networks.
- **Congress can also expand opportunities for training teachers by satellite, microwave, or other distance learning technologies.** Current funding for "Star Schools" could include teacher education programming, and funds for other demonstration programs could be increased.

Finally, in considering ways to expand teacher training, Congress should be aware of the role played by the private sector. Computer companies and software developers, who want a market for their products, are also involved in training teachers and supporting their use of technology in the classroom. Apple, IBM, and Tandy, for example, offer discounts on hardware as incentives for teachers to use their technology. Several software publishers have reduced pricing on applications packages, e.g., word processing, database management, and spreadsheets, for the same purpose. In addition to sponsoring conferences and seminars, a number of companies publish guides or other resources especially designed for the teacher. These efforts, like industry cooperation in research and demonstration projects, are very important resources that should be encouraged.

Box l-E.--New York State Teacher Resource Centers and Electronic Networking

New York State's Teacher Resource and Computer Training Centers are professional development centers organized and run by and for teachers all across the State. The State has supported the centers since 1984. The centers have been extremely popular with both teachers and State education officials, as their rapid growth demonstrates. In 19$4, there were 44 centers, supported by a $3.5 million State grant. Today, the number of centers has more than doubled, and State support has grown to $15 million. Local funds and links with other projects augment the centers' resources and activities. The centers serve approximately 77,000 teachers.

The purpose of the centers is to give teachers a major role in their own professional development. Each center is run by a local governing board that assesses teachers' needs and training concerns, and sets policy for the center. At least half of the governing board members must be teachers from the area served by the center. Teachers generally conduct the courses for their colleagues after school, on weekends, during the summer, or during the school day, with provision made for release time and substitute teacher coverage. Most courses are free or available at a modest cost.

Coordination with local universities is encouraged, and one member of the governing board must be a representative from higher education. This has led to innovative bridges between preservice and inservice education. Experienced teachers from the public schools serve as adjunct professors and teach methods courses at the university. It has also led to better coordination and oversight of student teaching internships in the local schools.

Training and education in the uses of technology in the classroom is only one of six statutory purposes of the centers, but has, in fact, been a central focus from the start. Approximately 35 percent of the center activities have focused on technology. This interest in technology has evolved with the teachers' own changing perceptions of the role of computers in schools. Moving from "we need to know something about technology" to an interest in "computer literacy," the current focus is on "how can we use computers, videodiscs, and other emerging technologies effectively in the classroom?" Some centers offer outreach activities, with specially equipped computer buses that travel to remote locations to offer training to teachers on-site.

Telecommunications is a special area of interest. Some courses offered at one center are broadcast by satellite to teachers in other centers. In the process of learning how telecommunications provide access to a range of information services and databases, the teachers have also discovered how they can use electronic networks to communicate with each other without regard to time, space, and geographical location. The Teacher Center Electronic Network, now in its third year, currently links all the centers across the State. Some 20,000 teachers have received training in its use and are users, either on the electronic bulletin board or by participating in ongoing computer conferences within regions or in curricular areas. The network allows teachers to share ideas and support one another in developing materials, conduct collaborative research, or serve as mentors to their less experienced peers.

Many of the centers are involved in a network project focusing on students "at risk." Although the network was intended originally for the exclusive use of teachers, in this project teachers have opted to open the network to specially targeted students who are provided their own "kid-to kid" computer conference. The students have at least one class period a week of computer time in school to "talk" with other students about their communities, their problems, their goals, and daily activities. The students are developing not just a facility in using the computer, but also increased writing skills and "technology chutzpah" which greatly enhances their self-confidence. The teachers, often isolated and frustrated by their work with these most challenging of students, are encouraging one another, learning from one another, and developing an important mutual support group via the network.

SOURCE: OTA site visits and interview, August 1987.

EDUCATIONAL SOFTWARE

More than 10,000 software products intended for instructional or educational use with stand-alone computers in schools and at home **are** on the market today. These products, which come on standard floppy discs, typically aim at specific subjects, such as language arts or arithmetic (see table 1-2). They most often provide drill and practice. In some cases higher order skills such as hypothesis testing or concept development are featured, but such products are in very thin supply (see table 1-3). Advances in graphics and sound technologies have led to creative software for social studies, music, and other subjects that, unlike mathematics or business, are not commonly associated with computer-based instruction. While mathematics programs still dominate the market, generic programs for word processing and data management are among the best sellers; many teachers seem to appreciate software that affords them wide latitude in classroom application.

This industry, now a decade old, consists of about 900 suppliers, the vast majority of which are quite small, averaging two full-time employees. Although total annual sales have grown, and are expected to reach $200 million by fall 1988, there are indications that commercial success may come at the expense of creativity and innovation. While many software titles receive favorable ratings from review agencies and professional computing magazines, there is a general consensus among educators (and software publishers as well) that the quality of educational software could be much better.

Table I-2.—Distribution of Educational Software by Subject (N=7,325)

	Percent of programs[a]	Number of programs[a]
Comprehensive	6	427
Computers	5	331
English/language arts	12	894
Foreign language	5	356
Mathematics	27	1,971
Reading	12	869
Science	16	1,148
Social science	8	565
Other[b]	18	1,329

[a]The sum of the programs is greater than N because some programs are assigned to more than one subject category. Accordingly, the total of the percentages is greater than 100 percent. All percentages were rounded to the nearest unit.

[b]The Other category combines 13 subjects (agriculture, aviation, business, driver education, early learning/preschool, fine arts, guidance, health, home economics, industrial arts, library skills, logic/problem solving, and physical education), each of which accounts for less than 4 percent of the total number of programs.

SOURCE: Office of Technology Assessment based on analysis of data in the Educational Products Information Exchange, July 1987.

Table 1-3.—Distribution of Educational Software by Type (N =7,325)

	Percent of programs[a]	Number of programs[a]
Rote drill	15	1,107
Skills practice	51	3,708
Tutorial	33	2,447
Concept demonstration	3	216
Concept development	4	270
Hypothesis testing	1	91
Educational games	19	1,425
Simulations	9	669
Tool programs	11	807

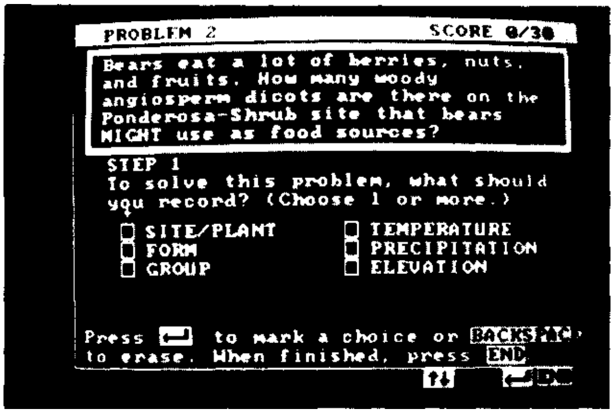
[a]The sum of the programs is greater than N because some programs were assigned to more than one category. Accordingly, the total of the percentages is greater than 100 percent. All percentages were rounded to the nearest unit.

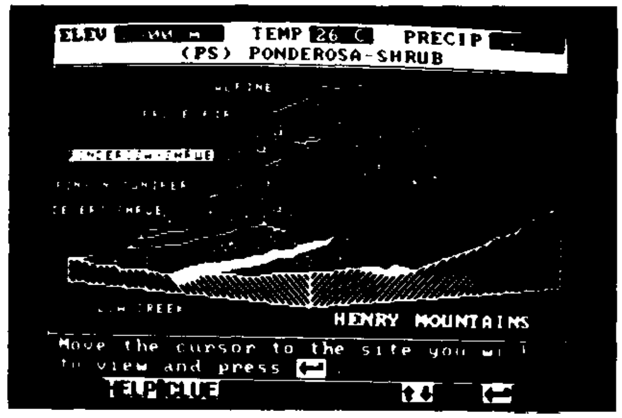
SOURCE: Office of Technology Assessment baaed on analysis of data in the Educational Products Information Exchange, July 1987.

What are the essential problems in this market? Aside from generic products that are applicable to many subject areas and grade levels, most instructional programs can reach only a small niche of the school system. Development and marketing costs are high relative to expected sales revenues. Surely some innovative products can become commercial “hits.” But, in general, software producers have a strong incentive to reduce costs and lower the risks of entering this market by producing software that is easy for teachers to adapt to their traditional curricula.

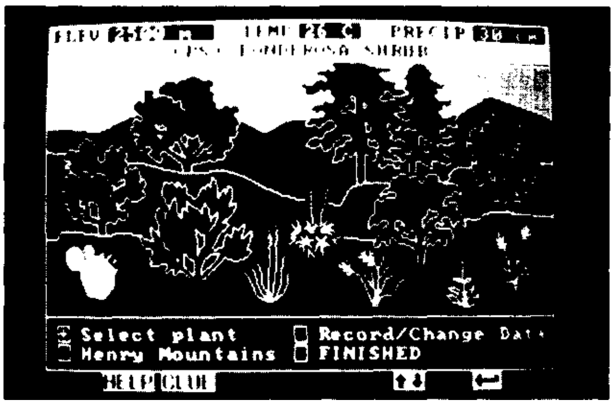
This propensity toward producing familiar instructional materials is not limited to small entrepreneurs. OTA finds that large firms, with greater capital resources, do not necessarily take larger risks; integrated learning systems, for example, have a greater chance of being attractive to school districts if their content is closely linked to textbook materials and tests. These systems, which are currently manufactured by about a dozen companies (with total revenues last year of about $100 million), have been provided in response to the call for greater accountability and improved performance on standardized tests, but they may be less well suited to educational improvement strategies that make the teachers more autonomous in the classroom.

OTA finds that software manufacturers tend to play it safe. They produce what teachers will buy,





Using the simulation “Henry's Plants,” they can observe plants growing on seven different sites in the Henry Mountains.



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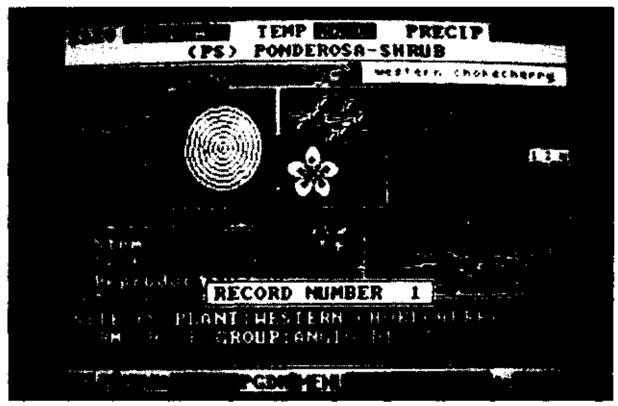

Students use the database to record the data they need to solve each problem. After gathering their data, they summarize their answers and receive a printout of the problem, data, and answers.

Photo *credit: Wasatch Education Systems*

In studying plant classification, students apply their knowledge by using a simulation and a database manager to solve problems in science:

and teachers usually buy products that are familiar. The potential result is a relatively homogeneous set of products that fall far short of the possibilities provided by the new learning tools.

The problem of a fragmented market is aggravated by information barriers, difficulties in enforcing intellectual property rights, and the incompatibility of hardware and operating systems. Knowledge of the idiosyncratic processes by which school districts around the country acquire instructional materials place experienced companies (textbook publishers, for example) at significant market advantage over newcomers; unauthorized duplication of software programs, as well as theft of broad software design principles, continue to plague the industry; and the presence of different computers in the schools, with different operating systems, raises development costs for publishers in pursuit of market share. The commercial market maybe viable, but there is substantial concern for the long-term quality and diversity of its products.

The continued development of affordable and effective educational software is critical to the success of interactive technology in schools. Yet, for all the reasons cited above, reliance on the private sector alone will probably not yield an adequately diverse, innovative, and responsive set of educational software products. State and local governments, and even the Federal Government, have roles to play in bringing forth affordable and effective educational software.

OTA does not suggest that the Federal Government go into the software development business. The following policies might be used to strengthen commercial development of these products:

- **Underwrite software research and development (R&D).** This is a "technology push" strategy that could reduce the risks faced by software developers. There are a number of existing programs available to provide support for software development: NSF's Advanced Applications of Technologies and the Instructional Materials Development Programs;[22] the National Aeronautics and Space Administration's computer software and interactive videodiscs materials development programs for space science and aeronautics education; the Department of Education programs for materials development for special populations (bilingual education, special education), and priority topics (at risk youth, drug education), as well as the Department of Education's research support to the Regional Education Laboratories and National Research and Development Centers; and the Department of Defense (DoD) R&D support for improved basic skills training and cognitive science applications for more powerful educational software.
- The **Federal Government could help States or districts develop joint mechanisms for defining software needs, encouraging developers, and acquiring software.** One effect of this approach would be to alleviate the difficulty software developers face in attempting to serve a fragmented market. Federal and State support need not imply Federal or State control of product development or utilization; school users should define their own educational software needs.
- **Support increased acquisition of more powerful and capable hardware.** This "market-pull" strategy would complement software development efforts. With more computers accessible to students, demand for educational software products will probably increase, which will in turn ameliorate the financial picture faced by potential developers.
- **Expand existing State programs for software review and evaluation.** One of the problems of software review is that it focuses on technical program qualities (such as screen resolution) rather than on instructional effects. But evaluating the latter is a much more costly undertaking, which the Federal Government could better afford than individual States. In addition, there is a need for more systematic dissemination of evaluation findings of various existing review organizations.
- **Fund research on "system portability."** If all schools used the same computer, software development costs would decrease. However, the choice of a standard might prematurely arrest hardware R&D, and might lock schools into systems that meet short-term goals at the expense of long-term progress. The Federal Government could reduce the problems arising from incompatible computer systems if it were to continue to support research on the development of transportable codes that would make programs written for one kind of computer compatible with other kinds of computers.
- **Develop effective intellectual property rights strategies.** Industry associations and academic consortia have been active in presenting to the public their case against unauthorized duplication of software. The Federal Government could help to facilitate agreements between State education agencies, software publishers, and school personnel on site-licensing, limited copying, and the development of pricing and distribution models that are compatible with the interests of software publishers and the educational community.

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[22]For example, a panel of education leaders and publishers convened by the National Science Foundation recently recommended that the government undertake innovative and risky development of comprehensive software in areas of critical national importance. The panel's principal finding was ". . . in the absence of private sector investment in the computer curriculum necessary for school superintendents to experiment with these options, the Federal Government should subsidize their development at an estimated cost of $20 million for eight secondary' school science and mathematics courses. " Arthur Melmed and Robert Burnham, New York University, "New Information Technolog, Directions for American Education, " report prepared for the National Science Foundation, December 1987.

RESEARCH AND DEVELOPMENT

The Federal Role

Today's most promising educational technology products are the result of Federal investments in R&D since the 1960s. These were developed with very modest levels of finding, and despite poor organization of the Federal R&D effort in education. Direct Federal funding of R&D for computer-based educational technology is about $200 million per year, a tiny fraction of the billions committed to other major categories of Federal R&D. Only $20 million of that is provided through the Department of Education. Investment in educational technology R&D has fallen since the mid-1980s. Federal policy for research on technology for the Nation's students has been and remains erratic and disorganized, making it difficult to move from basic research to development, testing, and dissemination.

There is no lead agency for educational technology and no coordinating structure across agencies. Despite this, individual agencies have played important roles. DoD took the lead in developing computer technology and applying it to education and training, beginning with early development of the computer and CAI. More recently, the military services have supported basic research in artificial intelligence, as well as developing prototypes and software for videodisc and interactive learning and training systems.

NSF has had a major impact on educational technologies in use in schools today, although funding has varied greatly and emphasis shifted widely over time. In the past 2 years, there has been a substantial increase in funding for advanced development of software and systems involving artificial intelligence, authoring languages, problem solving tools, tutors and expert systems, and applications of technology to formal and informal learning environments.

The Department of Education's research budget has always been a small percent of its overall funding, but even this figure declined dramatically in recent years. From 1973 to 1986, total Department of Education spending increased by 38 percent (in constant dollars). In the same period, research, statistics, and evaluation spending fell by 69 percent (in constant dollars).[23]

Viewed another way, these reductions in resources for educational research, statistics, and evaluation were more severe than for other Federal agencies with similar missions. Overall Federal research funds grew dramatically between 1980 and 1984, but funds for the National Institute of Education declined by 48 percent. Similar drops were reported for statistical and evaluation funding in the Department.[24]

The Library Wagon visits Black Rock School – A the foot of – 1904 – south Mt.

Photo credit: Office of Library Programs, US. Department **of Education**

American schools have long sought to provide the most up-to-date resources for education.

[23]Specifically, the National Institute of Education experienced a 79 percent reduction, The National Center for Educational Statistics a 65 percent reduction, and the Office of Planning, Budget, and Evaluation a 64 percent reduction in constant 1972 dollars. Eleanor Chelimsky, director, Program Evaluation and Methodology Division, General Accounting Office, testimony before the House Committee on Education and Labor, Subcommittee on Select Education, Apr. 20, 198S, p. 8.

[24]While the investment in statistical activity in other statistical agencies declined by 18 percent between 1980 and 1984, the National Center for Education Statistics experienced a 28 percent reduction. And while resources for evaluation in nondefense Federal departments and agencies dropped by 37 pm-cent, the Department of Education funds spent on evaluation contracts declined by 63 percent. Ibid, p. 9.

Support for R&D in technology dropped as well. Although important work was done on CAI in the 1960s, television programming in the 1970s, and new technology initiatives in the early 1980s, technology has been reemphasized by the Department since 1984. The Office of Educational Research and Improvement has supported few new technology projects.

In those instances where R&D funding for education has been focused and consistent in the Department of Education and the National Science Foundation, the results have been positive and dramatic. Examples include technology for students with special needs: the physically and emotionally handicapped and the learning disabled; the development of children's television programming from Sesame *Street* to *Square One TV;* and the development of LOGO.

Support from the private sector–industry and foundations–has also been important. Examples are many and varied, ranging from IBM's development of the *Writing to Read* program, Apple's Classrooms of Tomorrow, which explore how an intense computer environment affects teaching and learning, up to the recently created Institute for Research in Learning, supported by the Xerox Corp. Without such private sector support, educational technology would be greatly impoverished.

The Future of R&D

Research in the cognitive, social, instructional, and computer sciences is changing our understanding of learning and teaching. Such research investigates education from the learner's perspective, in contrast to the curriculum-centered approaches of past research. Using the learner as the focus of study, it examines the process of learning: the learner's initial level of understanding, how preconceptions or misconceptions affect understanding, where blocks to new understanding exist, and how these can be overcome.

This research, when combined with the power of computer-based technologies, has made possible the development of a number of promising innovations for education. These include:

- intelligent tutoring systems that can make the services of an expert and sensitive tutor regularly available to the learner;
- use of the computer as a flexible multimedia controller, adding the richness of video, graphic, and audio representations of information;
- simulations, exploratory laboratory experiences, and increasingly complex microworlds that build student understanding through exploration, manipulation, and guided discovery;
- integrated tools or "intelligence extenders" that enable learners to move from low-level tasks and concentrate instead on more cognitively demanding tasks;
- new assessment techniques that track learning, diagnose students' conceptual understandings, and evaluate the attainment of a range of skills;
- new design / knowledge kits that enable teachers to create and shape their own teaching materials; and
- new curricula based on a changing vision of skills students need in the information age, shifting emphasis from *what to learn* to *how to learn.*

OTA finds that the promising developments of learner-focused research will not reach full potential unless a number of important barriers are overcome. Researchers need costly hardware and advanced systems for R&D. There are shortages of researchers available to do interdisciplinary educational R&D. Extensive testing of materials and procedures in the schools is necessary. Technologies installed in schools today are not powerful enough to run sophisticated software applications suggested by advanced research. Commercial, industrial, and military applications have been the driving force in the marketplace for expert systems and other innovations; their requirements are seldom those of the schools.

Much closer ties between the research community and the classroom are needed. A new dialog must be established among teachers, researchers, and school administrators. Teachers need to be exposed to and be part of new breakthroughs in education; researchers need a healthy dose of classroom realities. Classroom trials are essential to ongoing development and necessary to assess what works. The problem is that this takes time and funding. Contributions from many disciplines will also be required.

OTA finds that, if educational technology is to reach its full potential, the level of funding for R&D must be increased. The Federal Government must take principal responsibility for research, development, and demonstration in educational technology. Very few States, and fewer districts or individual schools have the capacity to conduct large-scale research. They also lack the capacity and incentive to disseminate products and findings. Moreover, the needs and opportunities to improve learning cross district and State boundaries. Business and private foundations can and should be part of the R&D effort, but only the Federal Government can provide leadership, pull together resources, and coordinate dissemination of results. **Congress could build on existing programs:**

- **Increase funding and target research, development, dissemination, and evaluation in existing Federal R&D programs in various agencies. Congress could plan percentage increases in** R&D budgets for educational technology efforts in the Department of Education, NSF, and the basic cognitive science research components in DoD for individual researchers and research centers. These grants and contracts could require school system collaboration as well as require contributions from the private sector to leverage Federal dollars.
- **Set up mechanisms for Federal agencies conducting R&D in educational technology to pool resources, share information, and work more closely.** It is particularly important to encourage technology transfer from the military to the civilian education community, since the military funding for technology R&D in education and training is seven times that of the civilian sector. Cooperative efforts could include interagency funding and co-sponsored program meetings and conferences. Congress could also request an annual or biannual report that: a) reviews the activities of all Federal agencies involved in educational technology, b) identifies opportunities to transfer technology from one type of activity to another, and c) recommends future research.

Both these options could strengthen existing programs and allow for diversity of efforts. In light of the versatility and broad applications of new information technologies, diversity is desirable. However, these options carry the risk that technology efforts would have to compete with other Federal priorities for funding, as well as with one another, and no lead agency would emerge. Furthermore, interagency efforts are difficult to carry out. Moreover, without a concentration of resources and strategic planning on technology for education, it is difficult to make long-term investments. Valuable opportunities for education might be lost. **Congress could support new initiatives to make significant changes.** Policy options include:

- **Create centers for interactive technology and education.** Centers would conduct research, development, demonstration, evaluation, and dissemination of educational technology projects, and would be tied closely to schools. This option would expand considerably current Federal and private sector R&D efforts[25] in terms of the scale of effort, level of funding, and long-term commitment. Centers should make it possible to attract and retain the best and brightest researchers from interdisciplinary fields to oversee projects from initiation to final evaluation and to distill and disseminate information.
- **Create technology demonstration schools.** Demonstrations would marshal all school resources (equipment, curriculum, teachers, administration, community, and parental support) for integrating technology in the daily life of the school. Evaluation of the educational effects of a technology-rich school environment would be a key element, especially if these sites were connected to university and other research centers.
- **Develop a national education futures initiative that would include research, development, and demonstration in educational technology.** This effort would pull together at the national level research, development, and dem-- onstration; teacher training; software development in areas of critical need; longitudinal and comparative evaluations; and dissemination activities. Congress could include a sunset provision, perhaps using the year 2000 as an endpoint.[26]

[25] For example, the Department of Education's Educational Technology Center, or the newly formed Institute for Research on Learning, initiated by the Xerox Corp.

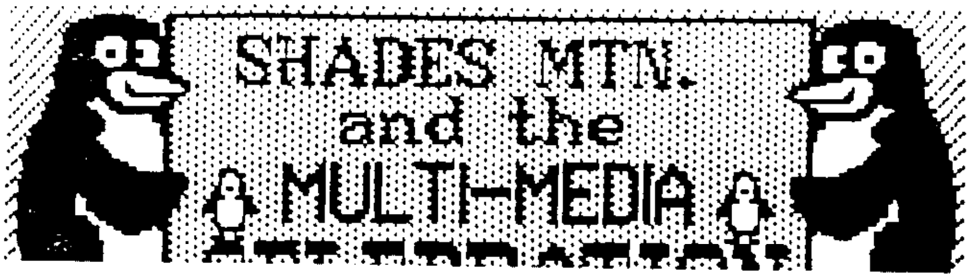
[26] Models for this level of effort include the Manhattan Project in atomic energy and the Apollo Mission to put a man on the Moon.

An effort of this magnitude would require establishment of a coordinating body or new institutional arrangement. One model is the British "quango,"[27] a quasi-autonomous nongovernmental organization that works closely with government on social policy issues. Such an education demonstration research corporation—with technology as a major area of study—could bring together educators, funders, program operators, and researchers to support basic research and carry out rigorously designed development, demonstration, and evaluation projects.

Both these programs sprang from a sense of national emergency and concentrated human, financial, and technological resources in a clearly articulated strategic plan of action. A national education futures initiative would not have the simply defined technical goal that characterized Manhattan and Apollo, but would focus national resources and provide momentum and commitment.

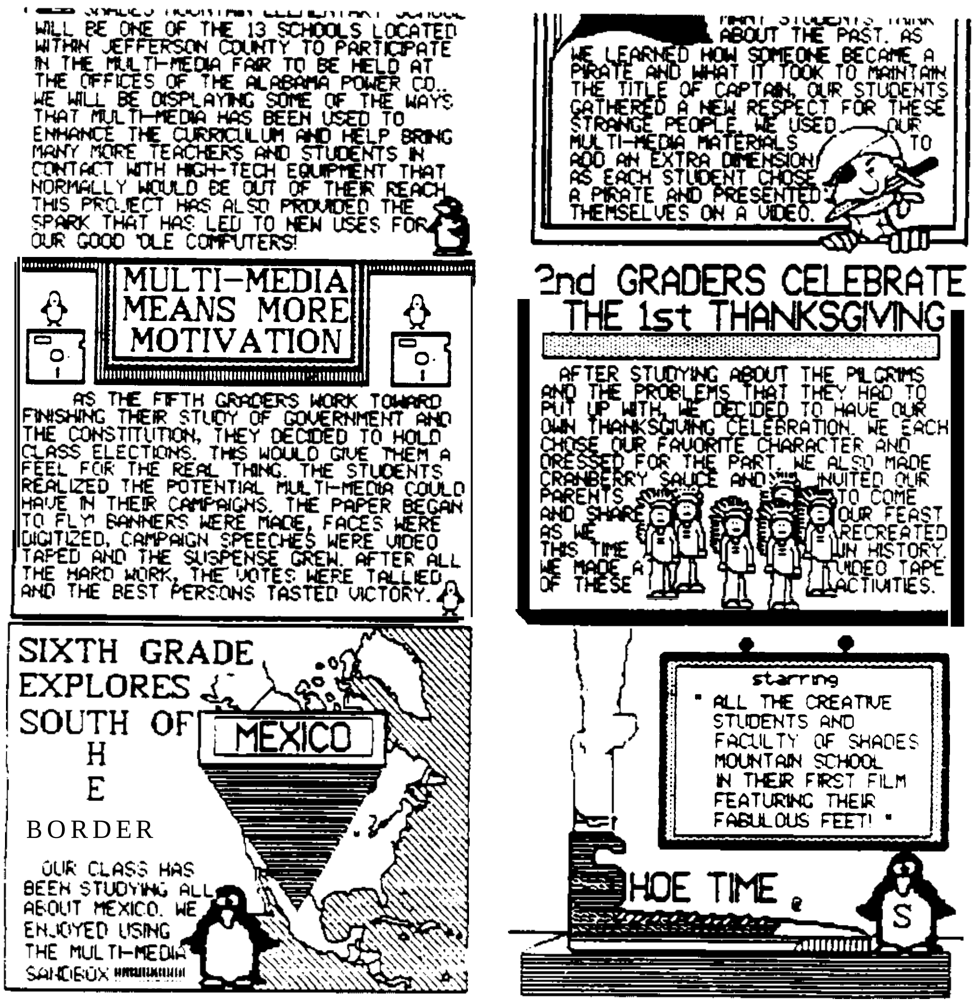
[27] Major R. Owens, chairman, House Subcommittee on Select Education, Committee on Education and Labor, "Opening Statement, " Oversight Hearings on the Office of Educational Research and Improvement, Apr. 20-21, 1988.

Finally, Congress may wish to consider new initiatives in international cooperation for educational technology R&D. The European community, Canada, Australia, Japan, Israel, the Soviet Union, and other nations are embarking on major efforts to use interactive technologies to improve education. The United States and these countries have common concerns, experiences, and outcomes, despite varying educational goals and cultural differences. Congress may wish to consider U.S. involvement in cooperative efforts such as sponsorship of conferences, exchange of researchers, electronic networking, and joint funding of projects. There are models for international scientific cooperation although little has been done to date with cooperative activities in educational technology R&D. Congress may wish to study this issue further, to identify the U.S. position with regard to other countries and to consider ways in which international efforts could proceed.



Chapter 2

Interactive Technology in Today's Classrooms



Credit: *Shades Mountain Elementary School. Hoover,* ***Alabama***

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Chapter 2

Interactive Technology in Today's Classrooms

The information age has arrived, and most societal institutions are experiencing profound changes as a result.

Samuel Y. Gibbon[1]

FINDINGS

- There are currently between 1.2 and 1.7 million computers in U.S. public schools. Over 95 percent of all elementary and secondary schools now have at least one computer intended for instructional use, compared to 18 percent of schools in 1981.
- The current installed base provides an average of 1 computer for every 30 children enrolled in U.S. public schools. School size as well as socioeconomic status of students are important determinants of the ratio of students to computers. However, actual student utilization of the technology depends on many other factors, including the organization of computers in laboratories or classrooms, the availability of appropriate software, and the presence of qualified and interested instructors.
- Differences in access to computers between black and white students have abated as more schools have acquired computers. Gender differences in student access and utilization tend to dissipate when computer use is highly structured and closely linked to the curriculum.
- Acquisition of video technology by schools has grown appreciably, following the pattern of computer acquisition. Today some 91 percent of all public schools use video technology (videocassette recorders, VCRs) for instruction.

[1]Samuel Y. Gibbon, "Learning and Instruction in the Information Age," *What Curriculum for the Information Age?* Mary Alice White (cd.) (Hillsdale, NJ: Lawrence Erlbaum Associates, 1987), p. 1.

ADOPTION OF COMPUTER AND VIDEO TECHNOLOGIES: A DECADE OF GROWTH

Currently there are between 1.2 and 1.7 million computers in U.S. public schools.[2] Since the 1981 academic year, when data on computer use in schools began to be collected, the number of public schools with computers has grown from about 15,000 to about 77,000, representing an average annual increase of about 11 percent (see figure 2-1). Peak growth occurred between 1983 and 1984, when 55 percent of the schools without computers acquired at least one (see figure 2-2). There are now computers in at least 95 percent of the 81,000 public schools (see figure 2-3).

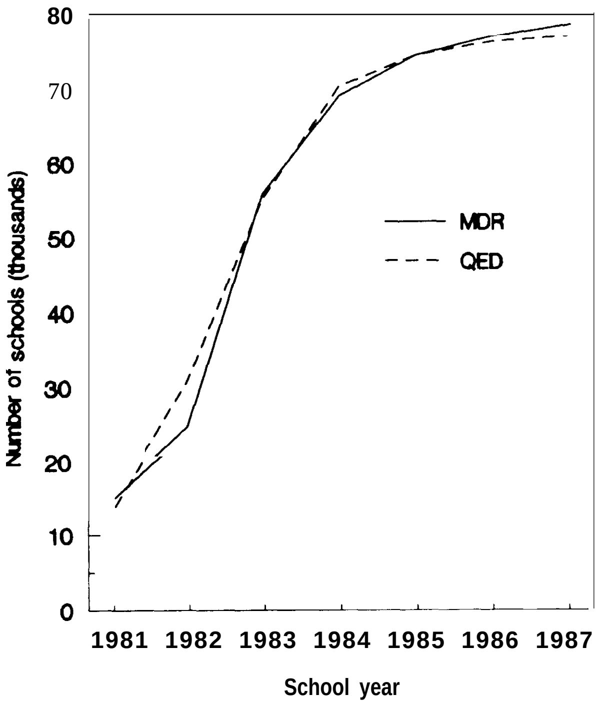
School adoption of the VCR, easily the second most prevalent new technology of instruction, started off a bit more slowly. In 1982, for example, when 37 percent of the schools had computers, only 31 percent had video. But by 1987, some 91 percent of schools were using video, close to the 95 percent that had computers[3] (see figure 2-4).

This record of growth is impressive, and clearly suggests a widespread willingness on the part of

[2]Market Data Retrieval, Inc. and Quality Education Data, Inc., the leading market research firms specializing in school technologies, estimate the 1988 total at about 1.2 million available for instructional use. TALMLS, on the other hand, a firm that collects data on the computer industry more broadly, reports a total current base of 2.03 million, of which about 375,000 are in private schools. Finally, *T.H.E. Journal,* a prominent educational technology magazine, reports the highest figure, 2, 1 million overall, with 1.7 million in the public schools, based on their recent survey. Variations among these estimates are due largely to differences in sampling methodology and timing of surveys.

[3]Quality Education Data, Inc., personal communication, May 1988.

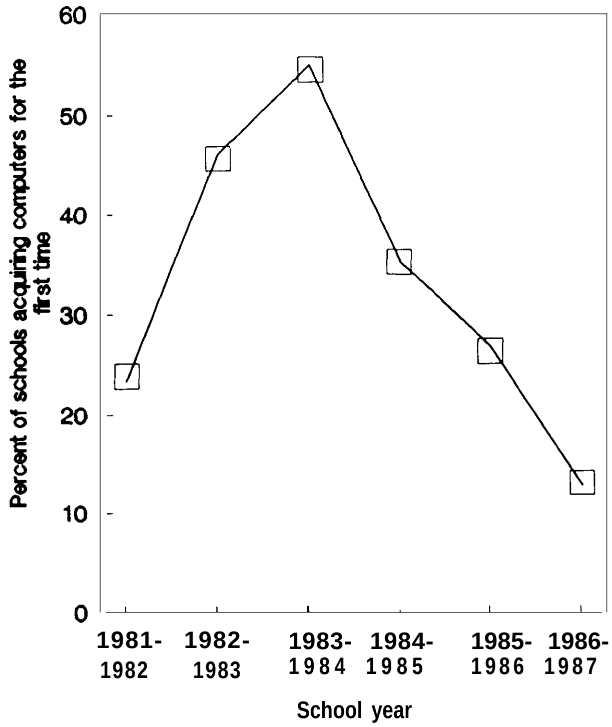
Figure 2-1.—U.S. Public Schools With Computers, 1987-88[a]



[a]Total number of U.S. public schools: approximately 81,000.

SOURCE: Office of Technology Assessment based on data from Market Data Retrieval, Inc., and Quality Education Data, Inc., 1988

Figure 2-2.—Annual Rate of Adoption of Computers in U.S. Public Schools, 1981-87[a]



[a]This graph shows the annual acquisition of computers among schools which had no computers in the previous year

SOURCE: Office of Technology Assessment based on data from Quality Education Data, Inc., 1988.

school districts, schools, teachers, and parents to explore the possibilities of the new learning technologies. Schools have not embraced the new information tools as enthusiastically as American business firms, where office automation and computer-based data processing are ubiquitous; but they have shown an extraordinary eagerness to adapt these technologies to classroom teaching and learning. According to at least one prominent educator and advocate of increased use of electronic information tools, the U.S. has quickly become a world leader in its attempts to integrate computer-based learning in public schools. [4] In a period of less than 10 years, computer-based technologies were introduced to students with quite different intellectual and behavioral needs by teachers and administrators of varied backgrounds, experience, and technical skill, working in schools of diverse demographic, racial, ethnic, and economic composition. Indeed, the available evidence points to a remarkably high rate of use: as of 1985, the latest year for which such data are available, less than 5 percent of the computers or terminals on school premises were not in use. [5]

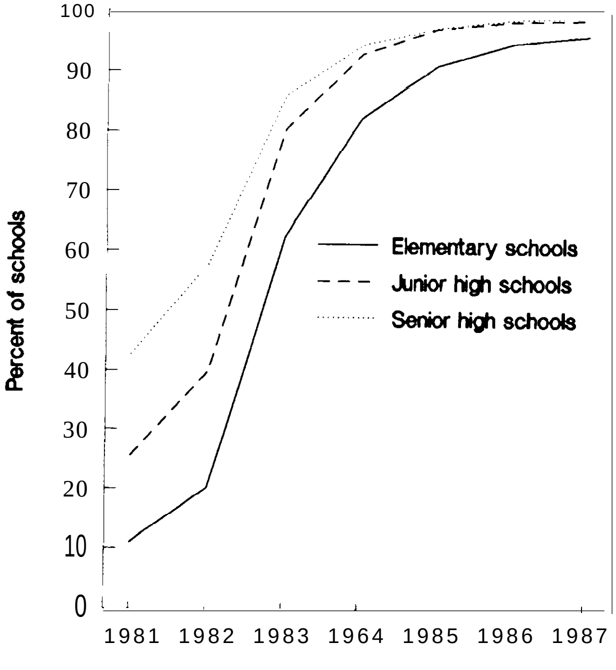
Effects of Widespread Distribution

These growth statistics tend to obscure an important fact about the rate and magnitude of computer acquisition. As of 1985, only half of the computer-using high schools and 6 percent of the computer-using elementary schools had 15 or more computers in any one classroom; it is doubtful whether all or even half the students in typical classrooms had ac-

[4]Speaking at the 1987 National Educational Computing Conference in Philadelphia, Mary Alice White noted that American public school adoption of computers in the last 7 years was the largest and fastest in the world.

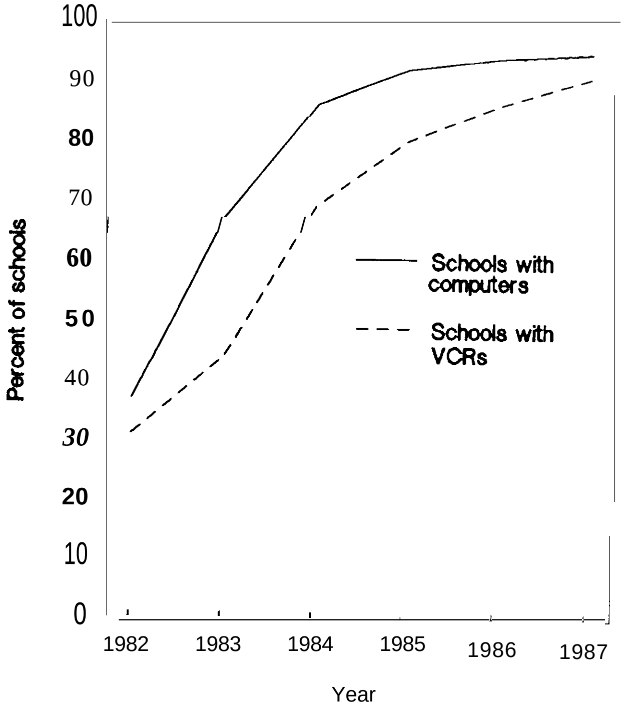
[5]This figure is based on unpublished data from Henry Becker's survey of school use of computers. For more information on this survey see Henry Becker, Center for Social Organization of Schools, The Johns Hopkins University, "Instructional Uses of School Computers: Reports From the 1985 National Survey," Issue No. 2, August 1986.

Figure 2-3.—U.S. Public Schools With At Least One Computer, by Grade Level, 1981.87



SOURCE Off Ice of Technology Assessment based on data from Market Data Retrieval, Inc , 1988

Figure 2-4.—VCRS and Computers in U.S. Public Schools, 1982.87



SOURCE: Office of Technology Assessment based on data from Quality Education Data Inc., 1988

cess to computers.[6] Most schools still do not have the quantity of computers that would be necessary to make them an integral part of the instructional day. Note, however, that the available data show differences by grade level in acquisition patterns and in the size of the installed base. As shown in table 2-1, very few elementary schools have a large number of computers, while over half the high schools do.

Broad diffusion of the new technology characterized the first decade of this instructional innovation. Perhaps a more selective introduction of computers and software could have been more effective at achieving certain well-defined instructional goals.[7] There is a general consensus, however, that decentralized acquisition and implementation created an exploratory atmosphere in which students' learning styles, teachers' pedagogical methods, and various approaches to software design could be tried.[8] Preliminary results from this "natural experiment" are just now coming in (see, for example, chapter 3), and while there is already a basis of data on which to formulate strategies for the next round of technology implementation and utilization, there is still a need for open-mindedness and ongoing evaluation.

Student Access to Computers

Today's inventory of school computers translates to a rough average of 1 computer for every 30 chil-

[6] Henry Becker, Center for Social Organization of Schools, The Johns Hopkins University, "Instructional Uses of School Computers: Reports From the 1985 National Survey," Issue No. 1, June 1986.

[7] See, for example, James W. Guthrie, "Campaign '88 and Education: A Primer for Presidential Candidates," *Phi Delta Kappan*, vol. 69, No. 7, March 1988. The author writes: "The prevailing strategy for introducing computers in U.S. education has not been to find effective ways to supplement human instruction, hut rather to ensure that each student has an **equal**, if inadequate, number of minutes each day on the computer" (p. 51 6).

[8] For an alternative view espousing greater State-level targeting of computer resources, see Stanley Pogrow, "Policy Recommendations for Developing Appropriate Uses of Technology in California Schools," testimony before the Assembly Committee on Economic Development and New Technologies, California State Legislature, on the Educational Technology Local Assistance Program, Jan. 5, 1988.

Table 2-1.– Distribution of Schools by Computer Inventory, 1987=88

	Number of computers					
Schools with computers	1	2-5	8-10	11-20	21+	Total
Elementary	5,388 (11.2°/0)	13,164 (27.3%)	13,059 (27.10/o)	12,647 (26.30/o)	3,900 (8.1%)	48,158
Junior high	354 (2.90/o)	1,636 (13.4°/0)	2,135 (17,5°/0)	3,505 (28.70/o)	4,592 (37.60/o)	12,222
Senior high	340 (2.30/o)	1,348 (9.0°/0)	2,073 (13.9°/0)	3,817 (25.60/o)	7,320 (49,1°/0)	14,898
Total schools with computers	6,082	16,148	17,267	19,969	15,812	75,278

[a]Excludes approximately 1,600 schools that are not classified as elementary, junior high, or senior high.

SOURCE: Office of Technology Assessment based on data from Quality Education Data, Inc., 1988 update.

Photo *credit:* Massachusetts *Institute of Technology*

Available evidence points to a high rate of computer utilization: as of 1985, less than 5 percent of the computers on school premises were not in use.

dren. Some teachers have turned this constraint into an opportunity by connecting the classroom computer to a large screen and involving the entire class at once in various learning activities. However, on average, computer-using students spend only about 1 hour per week on the computer. Between 1983 and 1988, the national average improved from about 92 students per computer to the current level (see table 2-2). In exceptional cases, each child has a computer at school and another one at home. But most schools still do not have sufficient quantities to allow most students in a typical class access at the same time (see table 2-3).

There is substantial variance in use of computers across schools of different size, demographic composition, and location. As OTA reported in 1987,' school size is a significant correlate of computer ownership and pupil access. In absolute terms, small schools have fewer computers than large ones, but

[9]U.S. Congress, Office of Technology Assessment, "Trends and Status of Computers in Schools: Use in Chapter 1 Programs and Use With Limited English Proficient Students," staff paper, March 1987.

Table 2-2.—Average Number of Students Per Computer in U.S. Public Schools, 1983=87

Grade level	1983	1984	1985	1986	1987
Elementary	112.4	79.3	55.3	43.7	36.8
Junior high	92.3	61.2	41.6	32.9	27.6
Senior high	76.6	51.5	37.9	31.1	26.3
All	92.3	63.5	45.5	36.5	30.8

SOURCE: Market Data Retrieval, Inc., 1966.

Table 2=3.-Ranges of Student Computer Density in U.S. Public Schools

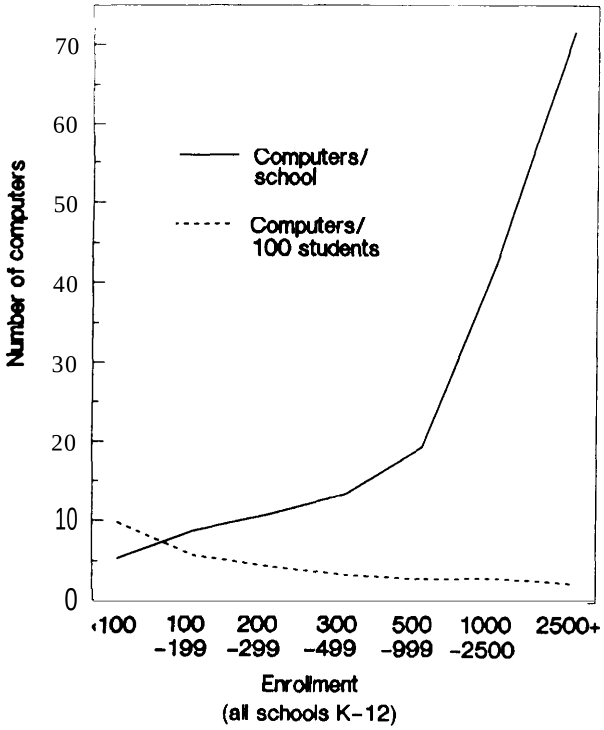
Students	Percent of schools		
per computer	Elementary	Junior high	Senior high
1-29	34.5%	43.4%	53.1 0/0
30-59	33.3	34.3	31.4
60-89	14.4	10.9	8.2
90-119	7.1	4.8	3.4
120+	10.7	6.6	3.9

SOURCE: Office of Technology Assessment based on data from Quality Education Data, Inc., 1968, smaller schools have *proportionally* more computers than large schools (see figure 2-5). Thus, students who attend relatively small schools are likely to have greater access to computers than students in large schools. This "enrollment penalty factor" was documented several years ago[10] and seems to have persisted even as overall growth in computer acquisition and utilization has continued. For example, as shown in figure 2-6, schools with 100 to 199 students on average have twice as good a ratio of students to computers as large schools with 500 to 999 students.

Because minority students are more likely to attend large urban schools, their access to computers has been worse than that of white students. This pattern is aggravated by the fact that wealthier schools have acquired technology more rapidly than schools with students of predominantly low socio-

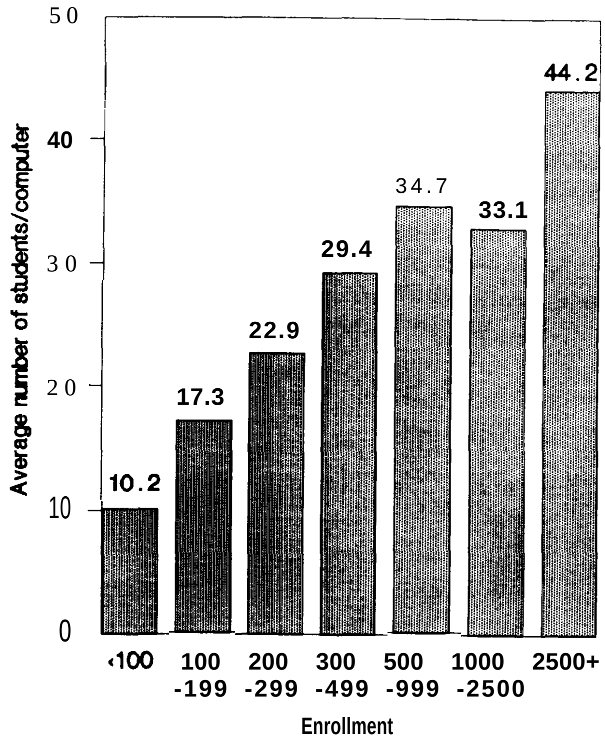
[10] Quality Education Data, Inc., Microcomputers and *VCR* Usage in Schools, 1985-1986 (Denver, CO: 1986).

Figure 2-5.—School Size and Student Access to Computers, 1987-88



SOURCE: Office of Technology Assessment based on data from Market Data Retrieval, Inc., 1988.

Figure 2-6.—Students Per Computer in U.S. Public Schools by School Enrollment, 1987-88ª



ªCalculations were based on a sample of 72,159 schools in the database for which all data were obtainad.

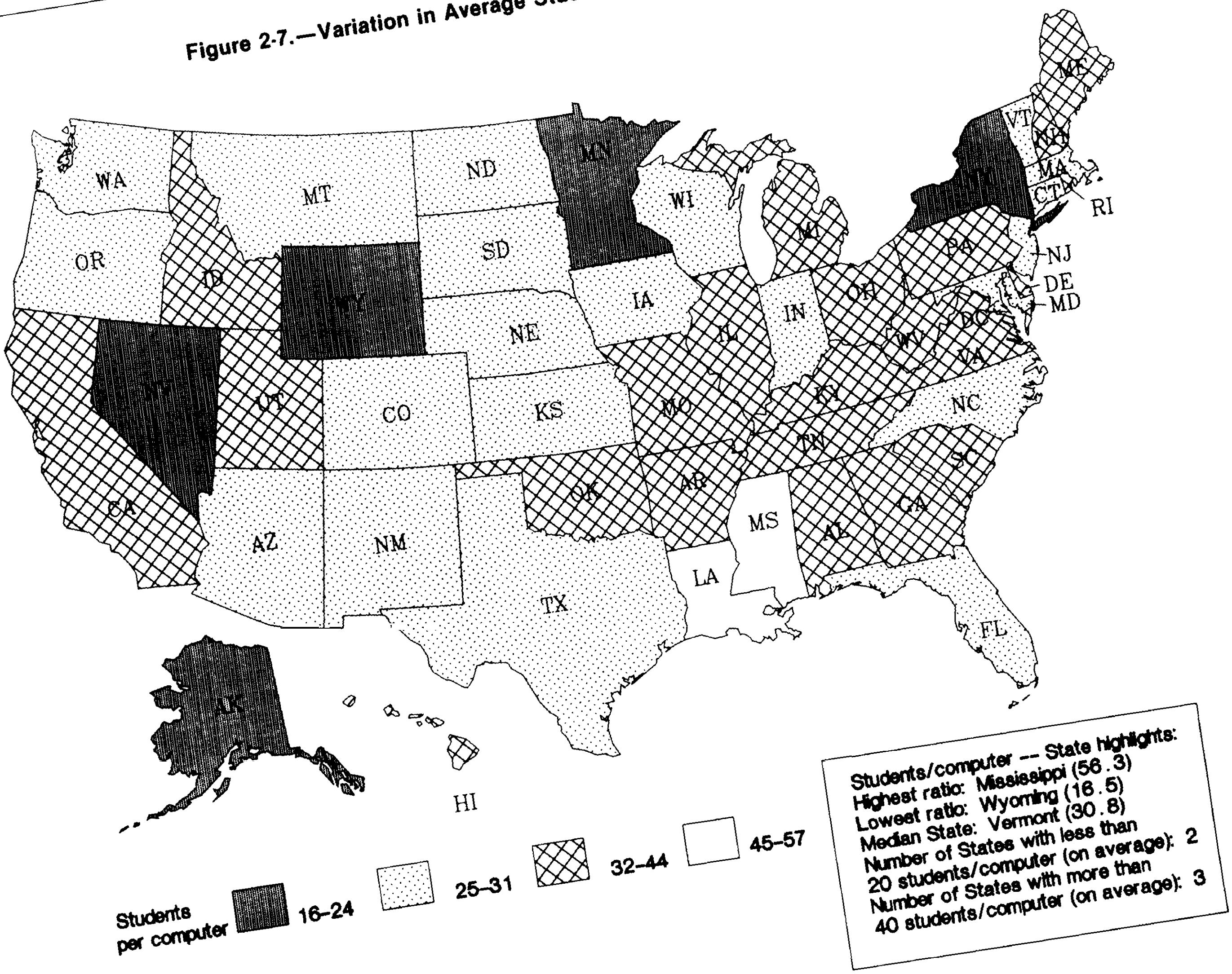
SOURCE: Office of Technology Assessment based on data from Market Data Retrieval, Inc., 1988.

economic status (SES). In addition, after controlling for SES and school size and location, all of which have influenced acquisition of new technology, OTA found from an analysis of 1985 data that predominantly black elementary schools were significantly less likely than predominantly white schools to have a computer.[11]

Average student access also varies by region, as shown in figure 2-7. It is interesting to note that access to video equipment varies by State, but that States with relatively good access to one type of technology do not necessarily do as well with other technologies. Alaska, for example, which was ranked first in average number of students per computer in 1986, was ranked 11th in average access to video

[11] Office of Technology Assessment, op. cit., footnote 9, pp. 28-29. Note that this problem has abated since 1985, because there are now very few schools left without any computers.

Figure 2-7.—Variation in Average Student-Computer Ratio by State, 1987-88



SOURCE: Office of Technology Assessment based on Quality Education Data, Inc., 1988.

equipment; and California, ranked 43rd in computer access, was number 8 in average student access to VCRs. Note also that these State rankings have varied over time, and that there is considerable within-State variance in student access.[12]

There has been much concern over the apparent tendency for school computer use to be dominated by male students. OTA has found that this phenomenon is abated when application of the technology is closely linked to the curriculum.[13] This poses a potential dilemma: a less structured approach to technology applications, as advocated by educational reformers who believe in increasing teachers' (and children's) classroom autonomy, may lead to unintended inequities.[14]

[12]Quality Education Data, Inc., op. cit., footnote 10.

[13]Becker, op. cit., footnote 5.

[14]For more discussion of gender differences see Office of Technology Assessment, op. cit., footnote 9, pp. 30-31; also ibid.

It is important to keep in mind that these estimates of student access provide rough measures at best. For example, while a school with 300 students and 3 computers has a better ratio (100 students per computer) than a school with 2,250 students and 15 computers (150: 1), access and use might be superior in the latter school. If the large school has acquired more sophisticated software, or has installed modern computer laboratory equipment (such as networking or communications devices), children in that school could benefit more from the technology than their counterparts in small schools which do not have the important additional equipment and which may not be as technologically advanced.

BEYOND COMPUTERS AND VIDEO

Computers and VCRs have become familiar fixtures in the American classroom. There is a strong belief on the part of many educators that these learning tools belong in the classroom, and there is widespread interest in understanding the conditions necessary for the new technologies to realize their potential. In addition, the rapid adoption of computers for classroom use has stimulated great interest in even more advanced systems, and in linking the powers of the computer to other communications and information technologies.

Indeed, much of the current school equipment is technologically crude compared to the advanced systems commonly found in business, scientific, and military settings. Computers typically found in schools, compared to typical office computers, operate with one-quarter the speed and about half the screen resolution quality. Thus, while these computers are being used in many areas of instruction, they typically cannot accommodate the latest developments in software that call for substantial storage and high-speed processing.

The new instructional technologies are costly. Even free-standing computer and peripheral equipment, such as disc drives and printers, can be taxing to local school budgets (see chapter 4). Nevertheless, advanced systems have begun to appear in some schools. For example, as discussed in greater detail in chapter 8, there are over 6,000 schools with modems,[15] and over 26,000 schools in districts with modems; 35 States currently support “distance learning” programs, many of which use satellite technology to bring instruction to children in isolated areas; there are roughly 650 school districts with satellite dishes; and some schools have installed networked systems of computers, which often include integrated instructional and classroom management software. At the same time, advances in software design, which tend to outpace the capacity of schools’ hardware, have shown how basic research in cognition and learning might be applied to classroom instruction. Some of the newest software exploits the increasing convergence among computer, television, and telephone technologies, embodied in such devices as the laser disc or the electronic bulletin board. But these systems are still prohibitively expensive for most schools.

At present, the most sophisticated technologies for interactive learning are still in the experimental stage—in the research laboratory and in a handful of classrooms, Their fuller implementation awaits continued evidence of their potential effectiveness, and will depend on an array of factors: their compatibility with teachers’ current and future classroom roles; the crafting of economic and organizational policies to stimulate the production and distribution of affordable and appropriate software; and research that blends laboratory findings with the realities of current and future classrooms. We turn now to these issues.

[15]Modems enable computer users to communicate over telephone lines. See ch. 8.

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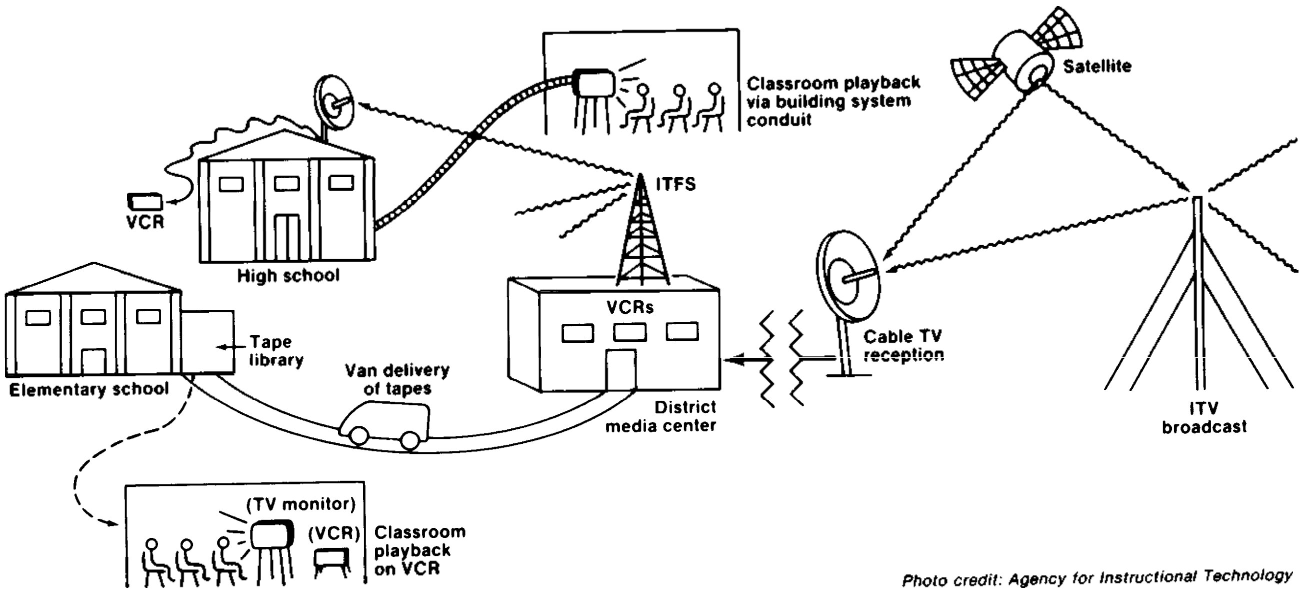

Photo credit: Agency for Instructional Technology

Thirty-five States currently support distance learning programs, many of which use satellite technology to bring instruction to isolated areas. This generic system combines broadcast or narrowcast with VCR use in a media center or class. Most systems have some, but not all, of these elements.

Photo credit: Bill Davie, Trinity Productions

Interactive television made it possible to offer a foreign language class for the first time in 20 years to students in Mackinaw City on Michigan's Upper Peninsula.

Chapter 3

The Impact of Technology on Learning

Photo credit: Stevens Creek Elementary School, Cupertino, California

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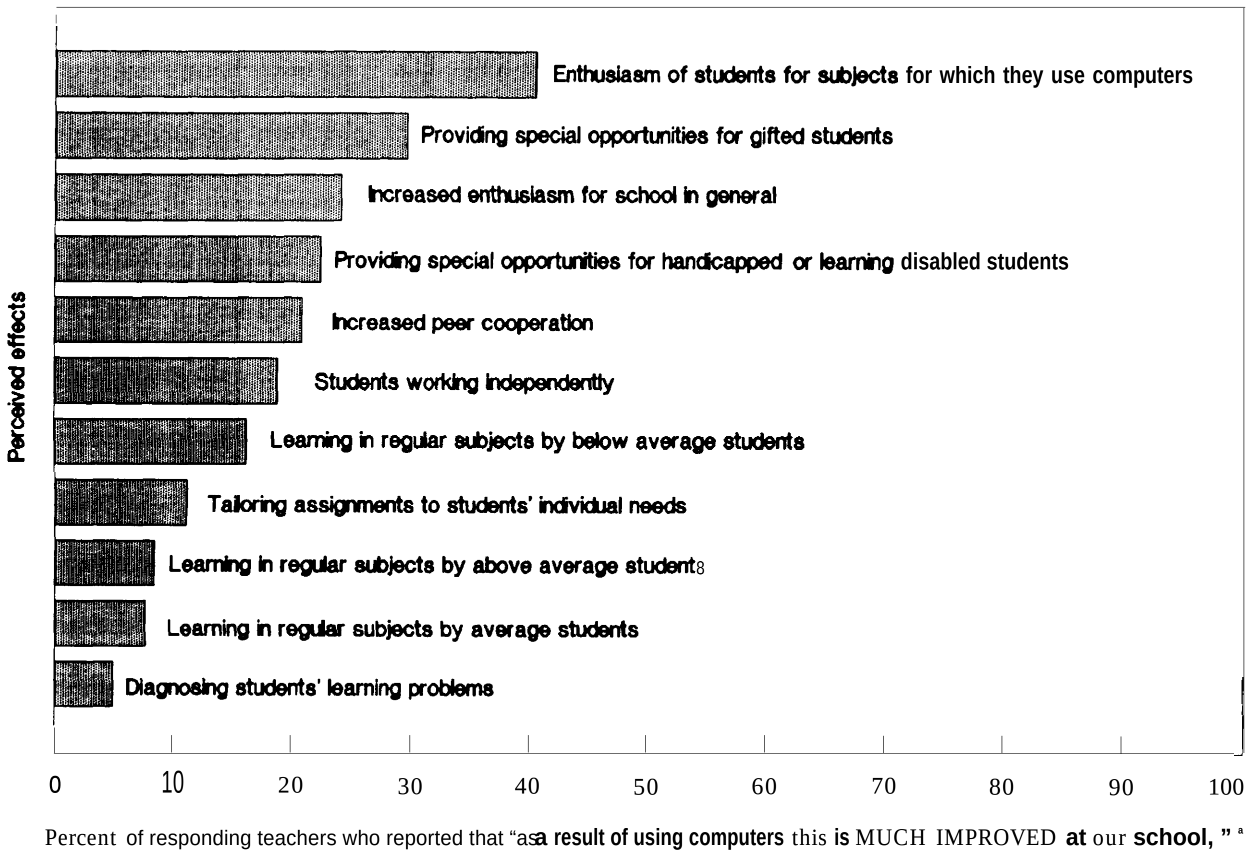
The Impact of Technology on Learning

INTRODUCTION

One of the most obvious questions about using interactive technologies in schools is, "Do they work?" Against a background of growing concern with the way American public school children are prepared for productive adult lives, computers and other electronic media have been hailed for their potential role in achieving a wide range of educational objectives. While only a handful of the most fervent visionaries think that technology alone can solve the difficult problems of American public education, many educators believe that interactive technologies can be an important element, if not the linchpin, in a broader program of organizational and substantive reforms. Surveyed for their perceptions of the effects of computers in the classroom, computer-using teachers supplied a long list of educational objectives for which they believe the technology has a positive effect (see figure 3-1).

Figure 3-1.--Teachers' Perceptions of Effects of Using Computers in Classrooms



[a]Respondents could have chosen "somewhat improved," "little changed," Or "negatively affected."

SOURCE: 1985 National Survey of the Instructional Uses of School Computers, Center for the Social Organization of Schools, The Johns Hopkins University.

Given the promise of technology, a sizable number of educational researchers have taken an interest in systematic and scientific evaluation. State and local education officials also want to know about the performance of these technologies as substitutes and complements for alternative classroom strategies.[1]

The basic question—"Do they work?"–covers the full spectrum of our expectations (and demands) of the schools: Do the technologies improve students' acquisition of basic language and computational skills? To what extent are children's higher order intellectual skills sharpened or dulled by exposure to computer-related systems? Are traditionally deprived children–those with physical, emotional, economic, or geographic disadvantages—reached more effectively by electronic learning tools than by traditional methods? Do the technologies help or hinder children's socialization skills and motivation?

By and large, the research to date supports the continued use of instructional technologies in the schools. But it is important to point out that questions of performance and productivity are much more easily asked than answered, in part because the near-term effects of educational technologies are not necessarily the same as the vision of what these technologies might achieve in the long run. For example, there is evidence that computer-assisted instruction (CAI) can raise achievement test scores for some students; but there is also wide agreement that computer technologies can already do more than provide electronic equivalents of drill and practice workbooks, and that much of their future promise lies in experimentation and development of nontraditional learning methods.

Without evidence of short-run gains, teachers and students will lose faith in the long-run possibilities of the new learning tools; if so, it will be difficult to garner the political and financial support necessary to realize the technologies' potential. On the other hand, if short-run effects are overemphasized, researchers and practitioners may lose sight of the longer-term potential, in which case the grander vision of the technologies' role in education will remain a vision.

This basic tension is manifest in much of the literature surveyed in this chapter. Many early studies of CAI, for example, relied on changes in standardized mathematics and reading scores as the criteria for effectiveness. This approach allows for rigorous measurement, because test scores provide a quantitative proxy for a range of cognitive outcomes; but there is concern with the validity of standardized tests generally, and with their impact on teachers' classroom strategies. Further, standardized tests are not indicators of long-run effects of interactive technologies on higher order analytical and language skills specifically. On the other hand, tests that could measure other goals of education, including motivation, creativity, and social behavior, are necessarily constrained by state-of-the-art measurement techniques.

The research reviewed here addresses a wide range of learning technologies, applied in many different settings with diverse populations of children and teachers. Although the results are somewhat scattered and impressionistic, they do suggest how certain configurations of hardware and software, used with particular populations of children and under the supervision of competent teachers, contribute to the achievement of specific instructional objectives. In the light of these considerations, **school administrators planning the implementation of a particular computer-based system need to tailor the application to their school's and students' needs,** and should not expect to see aggregate research results exactly replicated in their particular environment.

[1] The issue of cost-effectiveness, i.e., how the technologies compare to other methods per dollar of expenditure, is taken up in ch. 4.

FINDINGS

- CAI has been the most researched of the various interactive technologies. It has been demonstrated to be an effective supplement to traditional classroom instruction. In particular, elementary school children who used CAI showed gains equivalent to between 1 and 8 months of instruction over peers who received only traditional instruction. CAI may be more effective for low-

Photo credit: Kjell-Jon Rye, Bellevue High School, *Bellevue, Washington*

Hands-on technology applications provide meaningful contexts for learning and encourage students to learn from one another.

achieving students than for average and high ability students, even when controlling for base-rate differences between these groups. While most conventional CAI programs involve drill and practice, there is evidence that the method can be applied to improving higher-order thinking skills among disadvantaged children. A number of CAI studies have been challenged on methodological grounds.

- Intelligent CAI (ICAI), or intelligent tutoring systems, represent an attempt to apply advanced artificial intelligence techniques and theories of human cognition, and are considerably more complex than standard CAI. ICAI programs employ a wider variety of teaching strategies than conventional CAI, and allow for more thorough analysis of individual students' skills, knowledge, and problem solving processes. Some ICAI systems track an individual user's thought processes, identify problems, and provide specific exercises in response. Experimenters with ICAI have pioneered new approaches to teaching of mathematics, science, and language. These technologies, especially those that are based on so-called "natural language processing, " are still in their earliest stage of development.

- Effects of teaching computer programming *as a* means to learn analytical skills more generally are mixed. The possibility of using programming as a way to prepare mathematics teachers has gained credibility, although new and better research is needed. There is limited evidence that programming develops basic thinking abilities.

- Simulation programs have been effective in teaching principles in both the physical and social sciences.
- Microcomputer-based laboratories (MBLs)--probes and measurement tools attached to a computer for use in scientific, mathematical, or musical laboratories–have been shown to help students grasp complex concepts as well as to master important analytical techniques (like graphing). The skill of the teacher using the MBL is a critical factor.
- The teaching of graphing concepts stands out as an exemplary application of computer technology in the classroom.
- Database management programs have become very popular in classrooms. Limited research results suggest that students who use computerized data management systems outperform other students in tests of information processing skills, including identification of requisite information to solve a given problem and selection of efficient modes of organizing information.
- Word processing tools account for roughly 10 percent of the available instructional applications of computer technologies. While these tools do not, in and of themselves, create better writers, they have demonstrated their importance in easing the physical requirements of writing and revising. Both normal and learning disabled students who used the word processor as a supplement to writing instruction made significant gains in writing ability, compared to control groups that did not receive the computer-assisted intervention. In addition, the advent of word processing technology has stimulated new research on essential strategies for reading, critiquing, and revising one's own written work, some of which are now being incorporated into new writing software.
- Reading comprehension can be strengthened through computer-aided reading programs that aim to improve comprehension through interaction with the whole text. These include decoding and word recognition programs, text mediation programs, and speech synthesis. Disabled readers seem to enjoy using these technologies, and have made progress in important aspects of reading.
- Electronic networks—local, national, and international—build cultural bridges that connect children working on different types of projects in different places. Several science-related communications networks are particularly promising. In addition, these systems offer a form of "distance learning" to children and teachers in remote rural areas.

EVALUATION RESEARCH: **SCOPE AND METHODS**[2]

Most of the data on the effectiveness of educational technology comes from research on the uses of computers to enhance learning. The computer has several unique features relevant to education. The computer interacts: students provide information to the computer and receive immediate feedback. The computer is precise: learners must be specific and precise in their instructions or responses. The computer is consistent: instruction and feedback provided in a computer program will be the same for every student who interacts with that program. In addition, the feedback a student receives is private. Children do not risk public criticism and embarrassment with a response, and they often have many chances to try again. The computer can provide multiple and dynamic representations of a concept, phenomenon, or a relationship.

Over the past 30 years, computers have been used in education primarily to provide drill and practice or to convey traditional course content. These uses of the computer had the benefits of releasing teachers from the drudgery of drill and practice, freeing them to work with other students on more complex material, and motivating students to attend to otherwise tedious learning tasks. These early uses of the computer did not necessarily address the more creative, reflective, or meaningful aspects of learning.

[2]The remainder of this chapter draws heavily on Joanne Capper, Center for Research Into Practice, "Computers and Learning: Do They Work? A Review of Research," OTA contractor report, Jan. 21, 1988.

It is only in the last few years that computer use has moved beyond this workbook approach to learning. Only now are there more than a few software and computer applications that encourage the active construction of knowledge, provide meaningful contexts for learning, promote reflection, foster intellectual work similar to that encountered in an adult's work world, and free students from many of the tedious aspects of learning,

There are several approaches to studying the effects of computers in the classroom. [3] Cognitive researchers focus on the intellectual processes that are tapped by the computer. Their focus is often the individual student engaged in a problem solving task. Because research in cognition has successfully explored the finer-grained aspects of teaching and learning, it has been able to contribute to some of the more sophisticated developmental work with computers. The strength of this line of research is that it can tell us how something works (e.g., a piece of software) and why it affects learners that way—valuable information to guide future efforts.

Other studies consider how the technology or the software is used by individuals, by small groups of students, or by entire classrooms. Often the intent of this type of research is to improve the software or computer application, or to determine the extent and type of training needed to support teachers in their use of the technology. Some studies of this sort explore the contextual factors that influence how computers are used in schools—factors such as district support, extent of resources (hardware, software, and training), or equity issues. Traditional experimental studies where computer-using students are compared to control groups of students working on the same topics without computers can reveal whether or not a treatment worked in a particular setting; but they usually omit information about why a particular treatment worked.

Current testing techniques are relatively advanced in assessing whether or not students have learned basic content knowledge, but are still immature in assessing more complex thinking skills and changes in attitude toward learning. Many computer applications aim to enhance complex types of thinking and problem solving abilities. Without appropriate techniques to measure these abilities, we can only infer effects. Consequently, the research findings reviewed in the following pages are limited to effects that can be currently measured.

[3] The review of research that follows is intended to be Illustrative rather than comprehensive. The studies described were selected to give the reader a sense of the type of research underway and the trends that are emerging from the results of that research.

The methods used for identifying sources consisted of: 1) Educational Resources Information Center (ERIC) and library searches; 2) references cited in research articles; 3) telephone calls to funding agencies (U.S. Department of Education, the National Science Foundation, and the Office of Naval Research); and 4) telephone calls to researchers regarding the status of their work and to identify others working in the field. The latter two methods were found to be the most efficient in that funders and researchers tend to be familiar with the work of their colleagues.

The primary focus of this review is computer-tool applications as used in basic subject areas. The areas not addressed include: computer use at the college and university level; computer use in military training; Instructional design issues social, affective, and equity issues video discs; distance learning modeling; and computer applications in art, music, foreign language, or vocational education.

COMPUTER-ASSISTED INSTRUCTION

For almost 30 years, computers have been used to provide instruction and drill and practice in basic computation and language skills. CAI is the oldest instructional application of computers and the most researched.[4] The early CAI programs were provialed through large mainframe, time-sharing computer systems, operated and controlled from a central location. Examples of such systems include PLATO (Programmed Logic for Automatic Teaching Operations), created at the University of Illinois, and Stanford University's CAI project for elementary reading and mathematics skills.

[4] See, for example, P.K Burns and W.C. Bozeman, "Computer-Assisted Instruction and Mathematics Achievement: Is There a Relationship?" *Educational Technology* October 1981; Joanne Capper and Carol Copple "Computers in Education: Research Review and Instructiona Implications, " *The Research Into Practice Digest*, vol. 12, No 3, spring 1986; J.F Vinsonhaler and R.K Bass, "A Summary of the Major Studies on CA Dril and Practice," *Educational Technology*, vol. 12, 1972; Dean Jamisor et al., "How Effective Is CAI. A Review of the Research," *Educational Leadership, vol. 33,* 1975 and S.S. Hartley, University of Colorado, "Meta-Analysis of the Effects of Individually Paced Instruction in Mathematics," doctoral dissertation, 1977.

Until recently, mainframe or minicomputers were necessary to accommodate comprehensive and integrated curricula that could cover the entire grade span of an elementary or secondary school. With advances in memory and speed of microcomputers, however, and with the emergence of optical storage media (such as compact disc-read only memory, known as CD-ROM), integrated approaches to CAI no longer require mainframe computers: systems now being marketed by several companies use a microcomputer-based file server located in the same computer laboratory where the children work at terminals. While this change has brought about substantial cost reduction, it has not changed the basic philosophy of CAI, which involves a direct link between student and software and the transfer of basic instructional decisions from teacher to curriculum developer.

Even after the introduction of stand-alone computers (microcomputers), CAI programs remained little more than computerized workbooks. Information was presented on the screen, students were asked to indicate a response, and their response was evaluated. If the student was correct, he or she moved on; if incorrect, similar additional problems were given until correct responses were elicited. Many programs of this type are still used because they have proven effective when used in conjunction with traditional instruction.

Critics of CAI argue that drill and practice tasks could be done just as easily without computers. Another complaint is that CAI promotes passivity on the part of the user.

Advocates argue that many students who have not mastered basic skills can benefit from drill and practice, and that the computer helps to motivate students. In addition, the teacher is freed up to provide initial instruction and to work with individuals or small groups of children.

Hundreds of studies were conducted to determine the effectiveness of CAI. Several researchers have synthesized the results of a number of individual studies conducted at various levels to see if the results held up across studies. These syntheses reveal that elementary level students who received brief daily CAI lessons as a supplement to instruction showed gains equivalent to 1 to 8 months of instruction over their peers who received traditional instruction only.[5] However, when CAI is used as the sole basis for instruction, the results are mixed. Other findings show that CAI is more effective at raising achievement among low-achieving students than for average or high-achieving students, and that students complete material faster with CAI than with traditional instruction, sometimes as much as 40 percent faster. Increases in student attendance, motivation, and attention span have also been reported in most studies. Students who learned on the computer remembered as much of the ma-

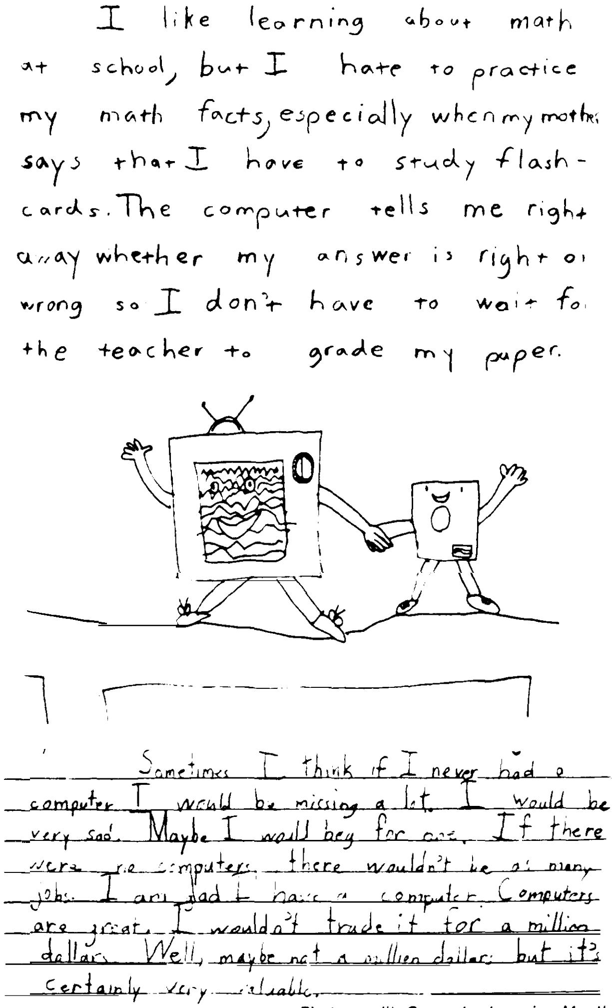


Photo credit: Computer Learning Month

Second graders' views of computers, submitted to the Computer Learning Month contest.

[5] James A. Kulik et al., "Effectiveness of Computer-Based Education in Elementary Schools," *Computers in Human Behavior, vol.* 1, 1985, pp. 59-7'4.

terial as did students who received traditional instruction only. Similar results were revealed in studies of CAI with secondary or college and adult populations, However, the gains in achievement were less significant.[6]

One criticism of CAI is based on a question of equity. Economically disadvantaged children and low-achieving children, many of whom are in federally supported programs (for example, under Chapter 1 of the Education and Consolidation Improvement Act of 1981), use the computer largely for drill and practice in basic skills. Gifted students, as well as children in predominantly white low-income schools, do less CAI and more programming than do students in predominantly minority elementary schools.[7]

It might be argued that low-achieving students are more likely to need the type of support provided by drill and practice. But while low-achieving students do need to master basic skills, they can also benefit from instruction that develops their higher cognitive abilities and learning strategies, Unfortunately, there is a tendency to consider such instruction beyond the ability of low-achieving students and to offer only gifted and high-achieving students such opportunities (with and without the computer).[8]

An exception is the Higher Order Thinking Skills (HOTS) Program developed at the University of Arizona. The program is designed to teach thinking skills to Chapter 1 students, primarily by teaching teachers to ask questions that elicit thinking responses. Teachers are also taught how to use selected software as the focus of Socratic dialogs with students. Early results indicate that Chapter 1 students enrolled in the HOTS program showed substantially greater gains on standardized tests when compared with the national average. According to its developer, the HOTS program is designed to develop thinking abilities among students in Chapter 1 programs.”

While the results concerning the effects of CAI are generally favorable, they are based on studies that have been frequently criticized on methodological grounds. One problem, for example, is that the computer treatments in some studies were supplementary while control treatments were not. Students using computers would receive 40 minutes per day in mathematics instruction, 10 of which would be devoted to drill and practice on the computer, while the control students would only receive 30 minutes of instruction. In this case, one cannot be sure that the increased performance of the treatment students was due to the extra 10 minutes per day or to the drill and practice on the computer. Would the results be so significant if the control students received an extra 10 minutes using flash cards or some other form of drill? Other flaws include disproportionate attrition from experimental groups, nonrandom assignment of students to treatments, incommensurable instructional content provided to control groups, and differences in relevant teacher attributes in control and treatment groups. In one review study, 26 out of 51 research reports were deemed unusable because of various methodological problems; however, the positive results of CAI remained stable even after eliminating the flawed studies.[10]

The main problem with the results of this 30-year body of research is that it provides no insight into how CAI produced those learning outcomes. It is only recently that researchers have begun to ask more useful questions, such as how and what students learn when they interact with computer-based instruction. A national field study being led by Henry Becker of The Johns Hopkins University

[6]Dean Jamison et al., “The Effectiveness of Alternative Instructional Media: A Survey,” *Review of Educational Research, vol. 44, No. 2,* 1974, pp. 1-6; D.N. Hansen, “Computer Assistance With the Educational Process,” *Review* of Educational *Research, vol. 36, 1966,* pp. 588-603; and David B. Thomas, “The Effectiveness of Computer-Assisted Instruction in Secondary *Schools,” AEDS Journal*, vol. 12, No. 3, 1979, pp. 103-115.

[7]Henry J. Becker, School *Uses of Microcomputers: Reports From a National Survey* (Baltimore, MD: Center for Social Organization of Schools, The Johns Hopkins University, 1983-1984), issues 1-6; and Elizabeth Reisner, *The Use of Computers in Instruction Supported Under Chapter 1 of the Education Consolidation and Improvement Act* (Washington, DC: Policy Studies Association, 1983).

[8]Beau F. Jones, “Quality and Equality Through Cognitive Instruction,” *Educational Leadership*, April 1986, pp. 5-11,

[9]Stanley Pogrow, “Preliminary Report on the Effectiveness of the HOTS Program,” unpublished data, 1987.

[10]Henry J. Becker, *The Impact of Computer Use on Children's Learning: What Research Has Shown and What It Has Not* (Baltimore, MD: The Johns Hopkins University, Center for Social Organization of Schools, 1987). *See* also Richard E. Clark, “Evidence for Confounding in Computer-Based Instruction Studies: Analyzing the Meta-Analyses,” *Educational Communications and Technology Journal*, vol. 33, 1985, pp. 249-262; and Patrick Suppes and Mona Morningstar, “Computer-Assisted Instruction,” *Science*, vol. 166, Oct. 17, 1969, pp. 343-350.

is designed to provide information about the features of various computer-based programs that influence learning. The study has a large and representative sample, will last 3 years or more, and will collect information on how various programs are implemented in different grades and for different subjects each year.

Intelligent CAI

ICAI is a branch of artificial intelligence devoted to developing instruction in curricular areas. The distinctions between CAI and ICAI are subtle and profound. With CAI, instruction is controlled by the developer of the program who determines what is presented, how much information is presented, the order of presentation, and the specific questions to which the student must respond. CAI programs cannot respond to students' questions, responses, or problems that are not specifically designated in advance by the programmer. ICAI programs, on the other hand, theoretically increase students' control over the machine and allow them the opportunity to *learn by doing.* Students interact with the computer rather than merely respond to it in a prespecified way; tutoring is often carried on in dialog form as a response to student input. In addition, ICAI is characterized by a far more thorough and fine-grained analysis of the skills, knowledge, and procedures involved in solving problems in a subject area. The strength of ICAI is not only the substantially more precise and detailed understanding of the nature of learning and problem solving, but also the ability of the program to *articulate,* or make *transparent* that understanding in a form that can be absorbed by the student. ICAI programs specify in detail a mix of three types of knowledge: the declarative knowledge (what), the procedural knowledge (how), and the metacognitive knowledge (thinking about what and how).

ICAI, also referred to as an intelligent tutoring system, can generate and solve problems, store and retrieve data, diagnose students' misconceptions, select appropriate teaching strategies, and carry on dialogs with students. In addition, intelligent tutoring systems employ a wider variety of teaching strategies than are likely to be found in a simple CAI programs. Many intelligent tutoring programs incorporate simulations and / or games that allow students the opportunity to "try out" their evolving models of knowledge in a domain.

Two science programs exemplify these advanced CAI efforts. Batteries and Bulbs, developed by researchers and educators at the Educational Technology Center at the University of California, Irvine, teaches electric circuitry in a way that conveys important aspects of the scientific method. It simulates electric circuit problems and students connect wires on the screen with the objective of lighting a simulated bulb. In addition, the program keeps track of a student's progress, offering assistance if a student consistently makes mistakes on a particular type of problem. Studies of Batteries and Bulbs show that students typically complete the program within an average of 2 hours and exhibit a qualitative understanding of terms such as "current" and "resistance," and a rudimentary understanding of a model of simple electrical circuits.[12]

QUEST is another program in electric circuitry that contains simulation activities, but unlike those in Batteries and Bulbs, the QUEST simulations allow students a variety of solutions to a problem while also designing an arbitrary circuit of their own that they can test through simulation. This aspect of the simulation works because all of the formal electrical laws of circuitry are built into the program and used to determine whether or not a circuit works. In addition, the "proof' or solution of a circuit is broken down and students can walk through a step-by-step, voice-simulated explanation of the proof.

The QUEST learning environment provides students with the opportunity to select from among several instructional approaches. For example, the open-ended exploration option lets students construct and modify circuits and test them with the simulation to see how they work, and with the problem-driven learning option, the system presents a series of problems for students to solve and gives

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[11] James L. Poirot and Cathleen A. Norris, "Artificial Intelligence Applications in Education," *The Computing Teacher*, August/September 1987, pp. 8-10. Much of the information in this section is drawn from Christopher J. Dede et al., Massachusetts Education Development Center, "Intelligent Computer-Assisted Instruction: A Review and Assessment of ICAI Research and Its Potential for Education, " unpublished manuscript, 1985.

[12] Alfred Bork, *Personal Computers for Education* (New York, Harper & Row, 1985).

computer-generated voice explanations of the solution when requested by the student. QUEST is based on cognitive research that identified the essential knowledge about electric circuits and the optimal way to teach that knowledge. As of fall 1986, seven students have worked with the complete QUEST program, and after 5 hours of "play," all of the students were able to answer simple questions about circuits and could troubleshoot for opens and shorts-to-ground in series circuits.[13]

Developers of intelligent tutoring systems have attempted to integrate findings from research on how novices learn and how experts solve problems. For example, a feature found in some programs is the *audit trail,* which leaves a record of a student's work as he or she progresses through problem solving. This trail allows students to look back over their own or other students' work and to reflect on the relative value of various approaches to problem solving. The intelligent tutoring system allows students to practice problem solving strategies, and is designed to diagnose errors and provide feedback when a student makes an error or needs help. The tutor does not intervene as long as the student generates correct solution steps. Box 3-A illustrates and describes how an algebra problem is solved with an intelligent tutoring program called the Algebra Tutor.

Similarly, the Geometry Tutor is an intelligent tutoring system that employs audit trails and is currently under study at Carnegie-Mellon University's Advanced Computer Tutoring Project.[14] It provides instruction in proving geometry theorems and focuses on teaching students to problem solve and to plan when they prove theorems. According to the authors of the Geometry Tutor, these skills are seldom emphasized in a standard geometry curriculum. Students often complete a geometry course with only a modest ability to generate proofs and little deep understanding of the nature of proofs. The Geometry Tutor monitors students while they are actually engaged in solving the problems and provides instruction and guidance during the problem solving process. Students do not have to wait until their papers are corrected to receive feedback. Feedback is immediate, precise, instructionally relevant, and based on a far more thorough analysis of problem solving behavior than would be possible with one teacher and a classroom full of students.

The Geometry Tutor was initially tested on a few high school students, some who had no geometry instruction and some who had just completed a high school geometry course. After 10 hours of instruction, all students were able to solve problems that their teachers considered too difficult to assign to their classes. In fact, a student who had almost failed geometry was successful, and the students considered their time on the computer as fun. The researchers are now testing the Geometry Tutor in a high school, comparing the treatment students' performance with that of a control group of students,

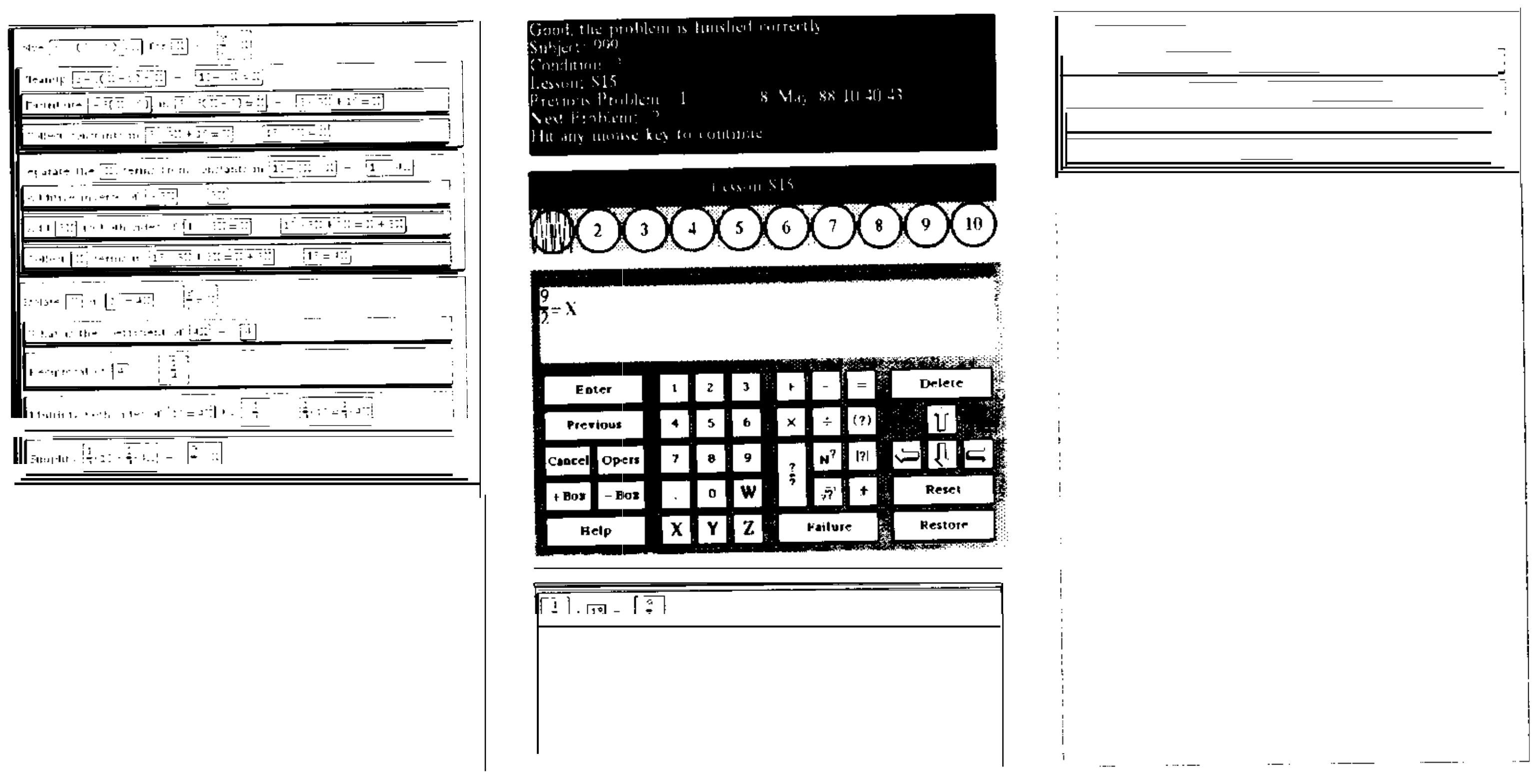
Other intelligent tutoring systems have been developed in a variety of areas. For example, SOPHIE (Sophisticated Instructional Environment)[15] provides students with a way to solve problems by trying out their ideas within the context of a simulated electronics laboratory. The system can answer students' questions, critique their hypotheses regarding why a piece of circuitry equipment is not working, and suggest alternative explanations. SOPHIE's ability to communicate with students depends on its natural language capabilities. The process of programming a computer to understand the ambiguities of natural language (English rather than Fortran) is one of the most intractable problems confronting artificial intelligence researchers today. SOPHIE approaches this problem by replacing conventional categories of grammar, such as nouns and verbs, with categories that represent concepts relevant to the SOPHIE system, such as circuit, transistor, or hypothesis. The system then attends only

[13] Barbara Y. White and J.R. Frederiksen, "Intelligent Tutoring Systems Based Upon Qualitative Model Evolutions," *Proceedings of AAAI-86: The National Conference on Artificial Intelligence* (Philadelphia, PA: American Association of Artificial Intellgience, 1986); and Barbara Y. White and J.R. Frederiksen, *Progressions of Qualitative Models as Foundation for Intelligent Learning Environments,* Report No. 6277 (Cambridge, MA: BBN Laboratories Inc., 1986).

[14] John R. Anderson et al., *The Geometry Tutor* (Pittsburgh, PA; Carnegie-Mellon University, Advanced Computer Tutoring Project, 1985); C.F. Boyle, "The Geometry Tutoring Project in Action," *Educational Leadership,* March 1986; and C.F. Boyle and John R. Anderson, "Acquisition and Automated Instruction of Geometry Proof Skills," paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, 1984.

[15] John Seely Brown et al., "Pedagogical, Natural Language, and Knowledge Engineering Techniques in SOPHIE I, II, and III, " *Intelligent Tutoring Systems,* D. Sleeman and J.S. Brown (eds.) (London: Academic Press, 1982).

Box 3-A.—Solving Problems With the Algebra Tutor



The algebra tutor begins by presenting the student with a problem to solve (solve for X: $3 - 3(X - 5) = X$). The student then uses a keypad to enter numbers or operations or selects operations from a menu. He or she can solve the problem immediately or go through a number of substeps. As long as no errors are made, the tutor does not provide any messages. However, if the student makes an error, is unable to go on to the next step, or asks for help, the tutoring system steps in to give immediate feedback or indicate the next step.

As students progress in expertise they begin to group problem solving into larger units (skip steps). The tutoring system is able to recognize skipped steps and adjust its instruction. The figure above shows two approaches to solving the same problem using a different number of steps. The audit trail leaves a record of the student's problem solving strategies.

SOURCE: Robert Milson et al., "The Teacher's Apprentice Project: Building on Algebra Tutor," Carnegie-Mellon University, Pittsburgh, PA, n.d. (Figure reproduced with permission.)

to the concepts it recognizes and tries to make sense of students' responses from those concepts, ignoring other pieces of information.

Impressive as this program might be, it is still a long way from understanding the subtleties of natural language. In fact, most artificial intelligence experts are cautious in their estimates of when, if ever, computers will really be able to cope with natural language.[16] Nonetheless, SOPHIE, along with other natural language-based tutors such as Writer's *Workbench* (AT-&T), *Critique* (IBM), and RINA (created at the artificial intelligence laboratory at the University of California at Los Angeles) have raised the hope that language barriers might be surpassed much the same way computers have overcome human limits to complex mathematical computation.

[16] Terry Winograd, an associate professor of computer science and linguistics at Stanford University, says flatly, "It's not in sight . . . it's not something that can be done by improving and tuning up existing systems.}' In B. Wallraff, "The Literate Computer," *Atlantic Monthly*, vol. 261, No. 1, January 1988, p. 11.

MATHEMATICS AND SCIENCE

Programming

For over 25 years, mathematics educators have advocated the use of programming for teaching mathematics on the grounds that, "Children who program solutions to science and mathematics problems develop a procedural understanding of the fundamental theories of these disciplines."[17]

The effects of using programming to teach mathematics at the elementary and middle school level are mixed, Two studies showed that students who did not use programming outperformed those who did, while two other studies found partial and limited support for programming, At the high school level, four studies found that students who received programming instruction in addition to mathematics instruction performed less well than did students without programming instruction. Two studies found partially positive results.[18]

Another use of programming has been to prepare student teachers to teach facts and concepts of mathematics. From one such experience the researcher observed certain essential difficulties for both teachers and students: 1) students who have problems learning mathematical concepts are likely to find programming concepts equally elusive, 2) additional and more complex cognitive effort is involved in establishing a connection between programming and mathematics, and 3) learning to program requires a great deal of time—time that could be devoted to learning mathematics.[19] Nevertheless, the idea that programming might be an effective vehicle to teach mathematics and to prepare teachers of mathematics is appealing and warrants ongoing study, perhaps along different theoretical lines.[20]

[17] Sylvia A. Shafto, "Programming for Learning in Mathematics and Science," paper presented at the Conference on Innovative Microcomputer Applications in School Programs, Friends School, Baltimore, MD, March 1985. See also National Council of Teachers of Mathematics, The *Impact of Computing Technology on School Mathematics: Report of an NCTM Conference* (Reston, VA: 1984); National Research Council, *Renewing U.S. Mathematics* (Washington, DC: National Academy Press, 1984); Conference Board of the Mathematical Sciences, *The Mathematical Sciences Curriculum K-12: What 1s Still Fundamental and What Is Not,* Report to the National Science Board Commission on Precollege Education in Mathematics, Science and Technology (Washington, DC: National Science Found ation, 198 3); and Richard J. Shumway, Ohio State University, "Mathematical Concept Learning *Through* Computer Programming: A Survey of Related Research," unpublished manuscript, 1985.

[18] Research on programming in middle schools is reported in D.F. Robitaille et al., "The Effects of Computer Utilization on the Achievement and Attitudes of Ninth-Grade Mathematics Students, " *Journal for Research in Mathematics Education*, vol. *8,* 1977, pp. 26-32; and D.T. King, "Research on Computers in Mathematics Education," *The Use of Computers in Mathematics Education Resource Series* (Columbus, OH: ERIC, 1973).

High school results are discussed in S.M.Katz, Temple University, "A Comparison of the Effects of Two Computer Augmented Methods of Instruction With Traditional Methods Upon Achievement of Algebra II Students in a Comprehensive High School," doctoral dissertation, 197 1; R.F. Ronan, University of Michigan, "A Study of the Effectiveness of the Computer When Used as a Teaching and Learning Tool in High School Mathematics, " doctoral dissertation, 1971; and Larry L. Hatfield and Tom E. Kieren, "Computer-Assisted Problem Solving in School Mathematics, "journal *for Research in Mathematics Education, vol. 3,* 1972, pp. *99-112.*

[19] J.B.H. duBoulay, "Teaching Teachers Mathematics Through Programming," *International Journal of Mathematical Education in Science and Technology*, vol. *11, 1980,* pp. 347-360.

[20] See, for example, G. Blume, " A Review of Research on the Effects of Computer Programming on Mathematical Problem Solving, " paper presented at the annual meeting of the American Educational Research Association, New Orleans, 1984.

Employability

Programming has been taught in schools in part to enhance students' employment opportunities after graduation. Researchers at the National Commission for Employment Policy examined the need for computer skills in the work force and concluded that only about 1 percent of the work force will require long periods of computer training (for example, engineers and scientists who design computers, programmers, and system analysts). Another 1 percent will need to be able to write their own programs (for example, some engineers, scientists, technicians, and accountants). The remaining computer users, however, will learn their skills in brief, on-the-job training. These findings suggest that computer programming need not be part of the general curriculum but should be part of a total training package for occupations that require computer use.[21]

Programming and Thinking

Evidence to support the belief that programming develops students' thinking abilities is limited and mixed. One study found that students who learned BASIC did no better than control students on three problem solving subtests: understanding the problem, carrying out the plan, and looking back at the problem.[22] This result is supported by the finding that students who spent a year programming did not differ from control students in planning efficient routes for completing a set of chores.[23] Positive results were found in a large-scale study of LOGO in 15 schools over 7 months. The LOGO students showed significantly more improvement than did non-LOGO students on a test of nonverbal cognitive abilities, exhibited less reliance on their teachers, and showed more independent judgment.[24] In addition, 9- to 1 l-year-old students who received 1 year of instruction in LOGO performed significantly better than control students on two of four problem solving tasks.[25] Another study of 18 6-year-olds found that students who received 12 weeks of instruction in LOGO outperformed students who used the computer to study reading and mathematics in a CAI environment. Students were assessed on measures of creativity, metacognition (ability to monitor and evaluate one's own thinking processes), and on their ability to provide accurate descriptions—an important skill in programming. The two groups did not differ on general measures of cognitive development.[26]

Simulations

Computer programs developed to simulate complex processes that occur in the world are available in several disciplines, including the physical and social sciences. The computer simulates a process through a variety of activities, including writing messages, "acting-out" the process of a phenomenon through illustrations and animation, and drawing graphs based on simulated data. Examples of simulations range from programs that allow students to see how an object behaves in a Newtonian environment, to programs that allow students to play the roles of world leaders making important decisions.

Some simulations are able to represent complex scientific concepts in ways that are impossible without computers. These representations attempt to increase the understanding students have of concepts that have been traditionally quite difficult to grasp.

Physical Sciences

In physics, several pieces of software have been developed to simulate an artificial, frictionless world where the laws of Newtonian physics can be examined. Students can perform experiments and observe results that are not possible in a friction-filled, classroom environment. One study used two computer simulations to diagnose and correct first-year college physics students' misconceptions about speed

[21] Harold Goldstein and Bryna S. Fraser, *Training for Work in the Computer Age: How Workers Who Use Computers Get Their Training* (Washington, DC: National Commission for Employment Policy, 1985).

[22] M. Ford, Arizona State University, "Effects of Computer Programming on the Problem Solving Abilities of Sixth Grade Students," doctoral dissertation, 1984.

[23] Roy D. Pea and D. Midian Kurland, *LOGO Programming and the Development of Planning Skills,* Technical Report No. 16 (New York, NY: Bank Street College of Education, Center for Children and Technology, 1984).

[24] T.A. Swartz et al., "Looking Into a Large-Scale LOGO Project," paper presented at the annual meeting of the American Educational Research Association, New Orleans, 1984.

[25] Joyce Statz, Syracuse University, "The Development of Computer Programming Concepts and Problem Solving Activities Among Ten-Year-Olds Learning LOGO," doctoral dissertation, 1973.

[26] D. Clements and D.F. Gullo, "Effects of Computer Programming on Young Children's Cognition," *Journal of Educational Psychology,* vol. *76, No. 6, 1984.*

and force. In the speed study, racing cars moved across the screen representing relative motion; in the force study, rockets represented the principles of force as related to energy and momentum. Students clearly understood speed better after using the race car program, but did not improve in their understanding of force after working with the rocket programs.[27] High school students working with computer simulations to teach them to solve force and motion problems using Newton's laws of motion learned significantly more than students who did not use the program.[28]

Social Sciences

Noncomputer-based simulations have long been used to raise students' interest in and understanding of social studies. Although research indicates that simulations do not necessarily improve the learning of content or skills beyond conventional instruction, they do seem to increase students' motivation, attitude, and participation. Simulations can also be a more effective way to involve students in decisionmaking processes, and they help convey complex representations of reality better than print materials or classroom lecture and discussion.[29]

Graduate students and faculty at the University of Michigan have developed two computer-mediated social science simulations in which students play the role of national or world leaders engaged in governmental or international affairs. One simulation represents the United States Constitutional Convention. Another, *International Communications Simulation (ICS),* represents the Arab-Israeli conflict. Working in teams of five or more, each student assumes the role of a particular individual or group represented in the conflict, such as the president or king of the country, the defense minister, leader of a guerrilla group, or diplomatic envoy. Teams are dispersed over 15 States and countries, including Mexico, West German, and France; they communicate with each other and with university staff.

Nearly 120 schools have participated in ICS, and informal evaluations have shown a number of positive effects. Students are more motivated to engage in high level critical thinking, have a better understanding of the dynamics of political affairs, appreciate the variety of perspectives on issues, gain experience with the computer and computer-mediated communications, develop insight into the research process, acquire research skills, have an opportunity to practice writing clear, forceful prose, and experience the challenge of making important decisions and the seeing the consequences of their decisions.

There are many types of simulations, but very few have been studied in a research setting. Because of the wide variability in the types of simulations, it would be difficult to generalize about the effects on learning of simulations in general.

Microcomputer-Based Laboratories

One of the more promising uses of computers is as a tool in the science laboratory. Scientists have been using computers to measure and graph phenomena for years, but they are just now making their way into classrooms. These laboratory tools, called microcomputer-based laboratories (MBLs), consist of probes attached to a computer. The probes, interacting with specially designed software, "sense" and measure various phenomena, such as light, heat, temperature, brain waves, pulse rate, and distance.

For example, students working with a sound probe can measure loudness or pitch, and the computer will record, display, analyze, and play back the sounds being measured. Students can try to produce a "smooth" graph by humming a pure note into the microphone—or can compare the graphs of high and low notes. They can measure the wave length of sounds that are an octave apart or compose a tune by plotting a graph of pitches they select. These activities help students to gain a sense of what is meant by the pitch of a tone.

Measurement is not new in school science laboratories. Students spend most of their time measur-

[27]Peter W. Hewson, "Microcomputers, Conceptual Change and the Design of Science Instruction: Examples From Kinematics and Dynamics," *South African Journal of* Science, vol. 80, 1984.

[28]Barbara White, "Designing Computer Games To Help Physics Students Understand Newton's Laws of Motions," *Cognition and Instruction,* vol. *1, No.* 1, 1984, pp. 69-108.

[29]Allen Glenn and Lee Ehman, *Computer-Based Education in Social Studies* (Bloomington, IN: Indiana University, Social Studies Development Center and ERIC Clearinghouse for Social Studies/Social Science Education, 1987); and Mark C. Schug and Henry S. Kepner, Jr., "Choosing Computer Simulations in Social Studies," *The Social Studies,* vol. *75,* September/October 1984, pp. 211-215.

Photo credit: **Marcia** *Linn, University of California, Berkeley*

Studies of microcomputer-based laboratories (MBLs) indicate that students using them grasp complex scientific concepts at a deeper level of understanding and become more proficient in using graphs than when MBLs are not used.

ing, recording, and graphing phenomena of interest; they often get lost in detail and lose sight of the experiment's focus—the concepts it is designed to convey. The computer can free up students to ask the "What if?" questions that characterize the practicing scientist's world.

A number of studies of MBLs in science laboratories indicate that students using MBLs grasp complex scientific concepts at a deeper level of understanding than when MBLs are not used.[30] In addition, MBLs have been successful in helping students to understand graphs–an important skill in learning science, but one that students often fail to master.

A critical factor in MBL use in the classroom is the way it is used by the teacher. Researchers examined a teacher's approach to using MBLs with various groups of students: one honors class, two average-ability classes, and one class of learning disabled students with average or above average intelligence. The teacher was most structured with the special needs students, discouraging them from exploring the equipment or from trying variations of an activity presented on the laboratory sheets. With the honors students, the teacher allowed substantially more autonomy. All students, except those in the special needs class, showed significant gains in their overall scores in mathematics skills and in understanding scientific concepts. The researchers plan to conduct further studies where learning disabled students use MBLs in an inquiry-based instructional setting.[31]

Educators and scientists generally agree that it is important for students to engage in a process of scientific inquiry. This is often characterized by extensive discussions where students attempt to construct defensible explanations for observable phenomena. Researchers noted that many teachers tended to use MBLs in a very structured way, with little or no discussions of experiments. In some instances, little time was devoted to independent exploration or experimentation. In fact, even projects that trained teachers in the use of inquiry-based instructional strategies for use with a particular computer application showed that teachers reverted to a procedural approach. (See box 3-B.)

Graphing

National test results show that students do poorly at graphing, despite the fact that graphing receives considerable attention in both algebra and geometry classes. Graphs are a powerful way to see functional relationships, for example, relationships between temperature change and time, or pulse rate and exercise. Students who have a solid grasp of graphing skills are more adept at studying changes in physical and social sciences.

The computer is an ideal tool for teaching graphing skills: it provides an instant representation of the relationships between variables and allows students to see graphs in real time as an experiment unfolds. The computer frees students from lower-level tasks (such as plotting points on a graph by hand) and allows them to focus on the more abstract, complex, and intellectually meaningful concepts. Results of studies where students use the computer to develop graphing skills are more consistently positive than any other area of computer use.

[30] Marianne Wiser, *Designing a Microcomputer-Based Laboratory To Induce the Differentiation Between Heat and Temperature in Ninth Graders,* Technical Report No. 85-15 (Cambridge, MA: Harvard University, Educational Technology Center, 1985); and Marcia C. Linn et al., "Cognitive Consequences of Microcomputer-Based Laboratories: Graphing Skills Development," *Journal of Contemporary Educational Psychology, 1986.*

[31] Janice R. Mokros and Deborah L. Levine, Technical Education Research Centers, "The Use and Impact of MBL as a Function of Learner Characteristics," unpublished manuscript, n.d.

Box 3-B.—Microcomputer-Based Laboratories in Practice

Tim Barclay, a researcher at the Technical Education Research Centers (TERC), a laboratory that has taken the lead in developing microcomputer-based laboratories (MBLs) for classroom use, characterizes TERC's view of how MBLs should be used:[1]

> MBLs are tools that have the potential to empower students to be scientists and creative explorers of the world. Being a scientist means investigating the natural world, asking your own questions, finding out 'what-happens-if.' Promoting inquiry in the classroom is a creative act, a process more easily described when it goes awry than when it's nurtured.

Barclay provides illuminating examples of procedural and inquiry classroom environments:

> In one MBL classroom at a large, suburban, junior high school . . . the teacher spent all the introductory time emphasizing a proper sequence of menu choices needed to follow the activity sheet instructions. When the students broke up into small groups, each with their own microcomputer and probes, the task had become 'do it right'. But what was that? They did not remember for sure what was right, and they did not read the instructions on the activity sheets either . . . . They called on the teacher: "What do I do next?" "Is this right?" "Why didn't it work?" Lacking any sense of the nature of the activity, the means had become a meaningless end. Completion was all; understanding was beside the point.
>
> A seventh grade class that used the MBL Sound Unit for several months is an example of tool-empowered inquiry. The two science teachers started by using the unit with their whole class as a group investigation. A single microcomputer was set up at the front of the class. Initially, the teacher posed the problems with the students suggesting how to find an answer and then using the probes to try it.
>
> As the unit progressed, students began to pose questions. The probe and the micro became tools for studying sound—sometimes to quickly show something, other times for an investigation that took up a whole class period. At the end of the sound unit, students did their own projects. These involved research and experiments and reports on topics that ranged from comparing the wave pictures from different musical instruments to analyzing bird songs. The teachers had made MBL their own, used it in their classrooms, and then passed it as a gift to their students to make into their own tool as well.

[1]The following quotes are from Tim Barclay, "Coping With Inquiry," *Hands On!* vol. 10, No. 1, newsletter of the Technical Education Research Centers, Cambridge, MA, 1987.

Sixth-grade students who worked in groups of three used MBLs to produce and observe graphs of motion in real time. The children's task was to produce a particular graph by moving about the room. This was possible because of sonar detectors and software that "sensed" the direction and speed of students' movements. For example, one student would play the role of the "dancer," moving about the room under the direction of two peers who offered advice about which way to move. When a graph was completed, students critiqued their own performance, and often, the dancer would beg for a chance to repeat the graph until he or she **was** satisfied with the results.[32] Students exhibited a solid understanding of distance and velocity graphs and achieved a mean score of 85 percent correct on a test of related graphing skills. Several other studies using MBLs to develop graphing skills show similar results.[33]

Game-like strategies are a second approach to teaching graphing skills. Programs called *Green Globs* and *Algebra Arcade* were developed to help students understand the relationships between algebraic equations and their corresponding graphs, This is based on the observation that one skill that seems to distinguish bright students with an aptitude for mathematics from other bright students who are less able in mathematics is their ability to look at polynomial equations and to quickly visualize what their graphs would look like.

[32]Ron K. Thornton, *Tools for Scientific Thinking: Microcomputer-Based Laboratories for the Naive* Science Learner, Technical Report 85-6 (Cambridge, MA: Technical Education Research Centers, 1985).

[33]Linn et al., op. cit., footnote 30; and Janice R. Mokros and Robert F. Tinker, "The Impact of Microcomputer-Based Labs on Children's Ability to Interpret Graphs," *Journal of Research in Science Teaching, vol. 24, No. 4, 1987,* pp. 369-383.

These computerized graphing games develop this ability by asking students to write an appropriate equation for a given graph. In *Green Globs,* the computer displays coordinate axes with 13 green globs scattered randomly on the screen. The student's task is to hit all of the globs with graphs that are generated by typing in equations. When a glob is hit, it explodes and disappears. The student's equation is instantly displayed in graphic form, so the student receives immediate feedback on his or her ideas (see figure 3-2).

One evaluation showed that students who regularly used *Green Globs* increased their graphing abilities more than control students who were unintentionally exposed to the graphing games for a short amount of time.[34]

[34]Sharon Dugdale and D. Kibbey, University of Illinois, Urbana-Champaign, "Prototype Microcomputer Courseware for Teaching High School Algebra," SED80-12449, final report to the National Science Foundation, 1980.

Algebra Arcade–an outgrowth of the *Green Globs* graphing program–was used with bright, female high school students who exhibited mathematics anxiety. Students who used the computer in this study were much more likely to explore relationships, try out ideas, try more experiments, and ask more questions, such as "If we made the numbers on the coordinates small by making the scale spaces large, would it speed up our calculations? What would we miss?" These results carried over to science laboratory investigations. The computer students were more likely to explore the differences in the interplay between phenomena and their representations in models, data tables, and graphs.[35]

[35]Mary Budd Rowe, University of Florida, Gainesville, "Computer Graphics in the Science Laboratory: An Experiment," unpublished manuscript, 1986.

MULTIMEDIA PROGRAMS

Several software programs have been developed in conjunction with videodisc and other media to provide learning environments in mathematics and science for students in grades 4-6. The ***Voyage** of the Mimi* was developed by researchers at the Bank Street College of Education, Center for Children and Technology. The instructional materials include learning modules, each with a different type of software and assorted print materials. The software models a variety of adult uses of technology, including a training simulation, a microworld, a programming environment, and a microcomputer-based physics laboratory. All of the video programs are closed-captioned in two languages: English and Spanish, and since one of the main characters is deaf, signing is used throughout. A key element of the design of the ***Voyage** of the Mimi* was the involvement of teachers throughout all phases of development.[36]

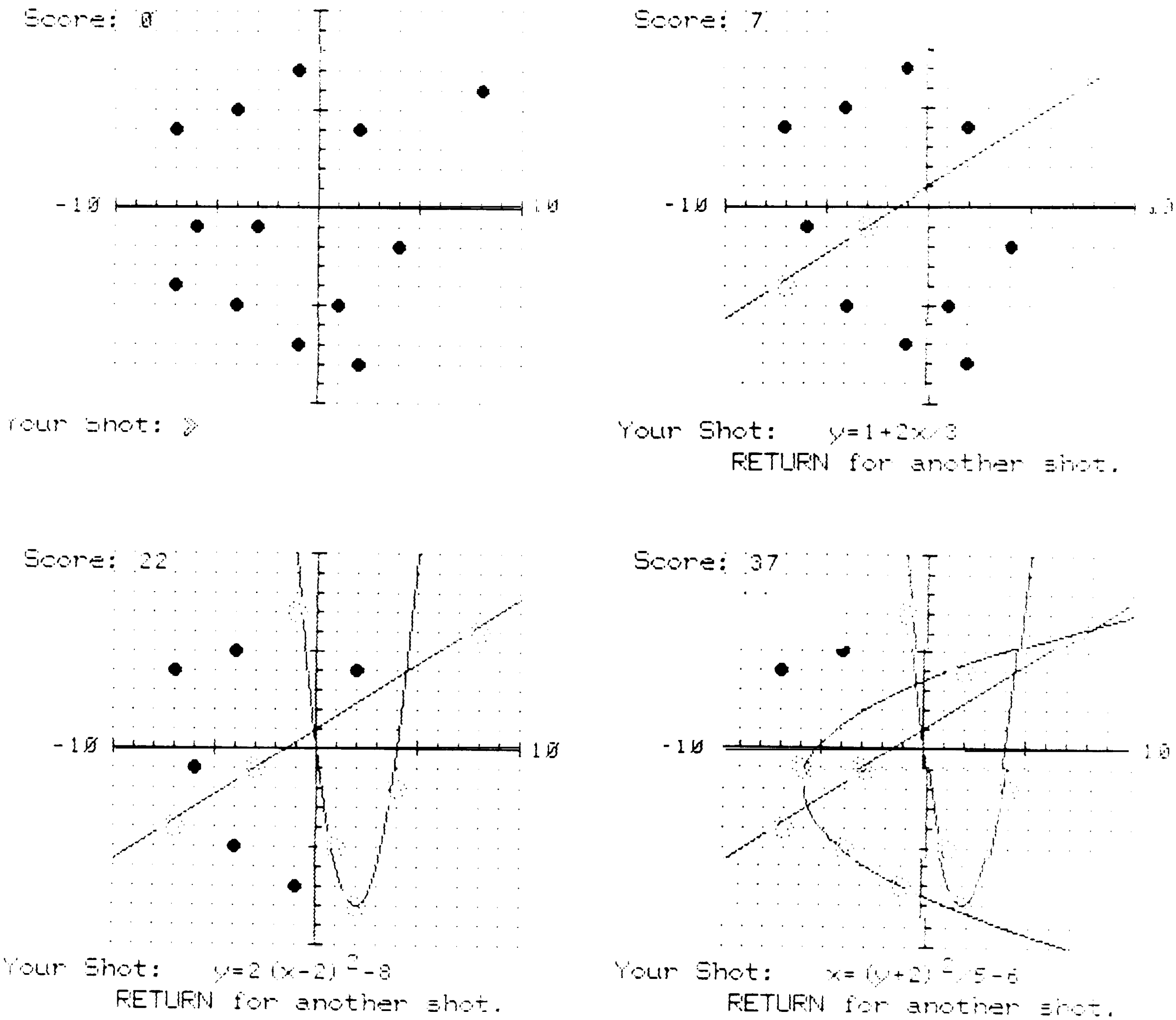
[36]Cynthia Char and Jan Hawkins, "Charting the Course: Involving Teachers in the Formative Research and Design of 'The Voyage if the Mimi'," *Children and Microcomputers: Theory, Research, and Development From Bank* **Street College's** *Center for Children and Technology* (working title), Roy Pea and Karen Sheingold (eds.) (Norwood, NJ: Ablex Publishing, in press).

The video documentary segments show scientists in their actual working environment; students get a sense of the scientific processes and procedures as they are used in real work situations. The learning modules include: simulation games of navigation problems; an MBL package for gathering and graphing temperature, sound, and light data; and a com-

Photo credit: **Agency** *for* **Instructional** *Technology*

While studying with the *Voyage of the Mimi* in school, Colby Leonard became "hooked" on science and built this bioshelter, a complete ecosystem, in his backyard.

Figure 3-2.—Graphing Equations Using the Computer



The student types in equations, which are graphed by the computer. The globs explode as they are hit by the graphs. Shown is the initial display of 13 globs, followed by the student's first three shots.

SOURCE: Displays of computer screens from Green *Globs* by Sharon Dugdale and David Kirby, reprinted with permission of the authors. For additional information see, Sharon Dugdale, "Green Globs: A Microcomputer Application for Graphing of Equations," *Mathematics Teacher,* March 1982.

puter simulation that allows students to explore the food chain, species populations, and the impact of human intervention on ecosystems. The software is accompanied by teacher guides that include a comprehensive discussion of whales (one of the major topics) and suggestions for classroom activities.

The learning modules were field tested over a 2-year period with 82 teachers and staff developers from 13 districts across the country to obtain their reactions to the videotape and software. The researchers observed the use of the materials in classrooms, conducted student and teacher interviews, and collected daily logs maintained by teachers regarding their perceptions of the materials as they were being tried out. The researchers conducted 1 week training sessions for teachers in the principles of inquiry-based instruction.

The integration of inquiry teaching strategies with the use of technology was the primary goal of the Mimi project. Inquiry teaching promotes an environment that tolerates ambiguity and encourages students' questions. The researchers found that few teachers were able to adopt or sustain a style of teaching that encouraged inquiry. Teachers tended to ask the majority of the questions and rewarded students for guessing correctly. Teachers required continual help in maintaining a classroom climate that emphasized reasoning rather than right answers, and only teachers who had experience in inquiry-based instruction used the materials in an open-ended way. The researchers found that it was important to provide training in the scientific concepts covered in the materials and to give teachers rich and varied suggestions for classroom activities. All teachers using the Mimi materials reported that they intend to use them again and recommended the materials to other teachers.

~Margaret A. Honey et al., "Teaching Technology: Creating Environments for Change," paper presented at the American Educational Research Association, Washington, DC, 1987.

DATABASE MANAGEMENT

Students in some classrooms use database management software to store, update, retrieve, organize, sort, format, and perform computations on data. Unfortunately, while there are numerous anecdotal reports enthusiastically describing their use in classrooms across the country, there is very little research documenting the effects of such tools in learning.

One of the few studies conducted on the use of databases involved 14 teachers and 665 students in grades 7 through 12. One group of students used a computerized database (PFS: *Curriculum Data Bases for U.S. History and for U.S. Government),* while the control students used the same curriculum-specific data printed on 4" x 6" index cards housed in plastic file boxes.

The key difference between the activities engaged in by the two groups was in the level of structure. Students in the computer group received detailed instruction in how to use the computerized database system to solve problems, define information, develop data retrieval specifications, interpret and evaluate retrieved data, and revise retrieval specifications. The control students did not receive similar step-by-step guidance in noncomputerized data management. In addition, the design of the database program imposed more of a structure in manipulating data than was possible with the students who used the index card system.

In a carefully controlled experimental design to test information processing skills, students using the computer database program in concert with structured activities significantly outperformed the control students. The specific abilities measured on the Information Processing Scale were: I) to recognize sufficient information to solve a given problem, 2) to recognize whether the information presented was relevant to a given problem, and 3) to discriminate between efficient and inefficient organizations of information to solve a given problem. '8

[38] Charles White, Indiana University, "The Impact of **Structured** Activities With a Computer-Based File Management Program on Selected Information-Processing Skills," doctoral dissertation, 1986. See also Charles White, "Developing Information-Processing Skills Through Structured Activities With a Computerized File-Management Program," *Journal of Educational Computing Research, vol. 3, No. 1, 1987.*

The use of database systems is likely to increase, especially as this tool will continue to play a central role in business management, science, and industry. Skills that students need in order to use these systems include the ability to:

- define a problem in specific terms, perhaps breaking it up into several small problems;
- identify specific data needed to address that problem;
- locate and extract relevant data from the larger collection of data;
- put the data in a useful order (e.g., by size, date, age);
- organize printed lists or arrangements of the data;
- use the information obtained to identify patterns such as relationships or trends (as well as cases that depart from the patterns);
- identify further information needed in order to explain, interpret or investigate cause and effect relationships; and
- communicate findings to others."[39]

[39]Beverly Hunter, "Knowledge-Creative Learning With Data Bases," *Social Education, vol. 51, No. 1, 1987. See* also M. Rothman, "Using the Microcomputer to Study the Anatomv of Revolution," *The Computing Teacher, vol. 10,* September 1982; Tama Traberman, "Using Interactive Computer Techniques to Develop Global Understanding," *The Computing Teacher,* September 1983; and D.M. Morrison and J. Walters, "IMMIGRANT: A Social Studies Simulation for AppleWorks," *Computers in the Classroom: Experiences Teaching With Flexible Took, C.* Thompson and L. Vaughn (eels.) (Chelmsford, MA: Northeast Regional Exchange, Inc., 1986)

WORD PROCESSING

Word processors offer writers ease in editing, neat printed copy, and tend to make the process of writing more public. They often incorporate features that hyphenate words and check on spelling, and some of the more complex correction programs comment on the screen about style and grammar, while others catch errors and report them to the writer. Students' writing does not necessarily improve merely by using the word processor. While students may be inclined to write more text, and enjoy writing more when they use a computer, students' corrections are often mechanical rather than substantive.[40]

A number of key differences in the writing and revision process of expert and novice writers have emerged from research on writing. Experienced writers revise extensively, while beginning writers tend to make superficial changes, such as spelling or word choices. In fact, beginning writers often do not even read over their text when asked to revise, but rewrite from memory. Revision is a complex cognitive process.[41] Young or novice writers may not know what to do when asked to revise. Revision requires writers to evaluate their writing, diagnose problems, and figure out how to correct the problems. Merely easing the physical requirements of writing does little to ensure that these cognitive abilities are developed.

Researchers have begun to identify key strategies that seem to be essential for reading, critiquing, and improving one's own written work, Some of these strategies are being incorporated into software programs for writing. For example, a program called Catch encourages students to take the point of view of the reader as they revise and prompts students to focus on the meaning of a passage rather than on its more superficial aspects. Studies with middle school students showed that students using the Catch software made more revisions from the original text when compared with students who used only a word processor. Revising in this manner also means that more changes can be made within the body of the text rather than by adding changes at the end. These results are particularly significant,

[40]Colette A. Daiute, "Psycholinguistic Foundations of the Writing Process," *Research in the Teaching of English, 1981,* pp. 5-22; Colette A. Daiute, "The Effects of Automatic Prompting in Young Writers," interim reports to the Spencer Foundation, 1981, 1983. See also R.M. Collier, "The Word Processor and Revision Strategies," *College Composition and Communication,* vol. 34, *1983,* pp. 149-155; and L. Bridwell et al., "Revising and Computing: Case Studies of Student Writers," *The Acquisition of Written Language: Revision and Response,* S. Freedman (cd.) (Norwood, NJ: Ablex, 1985), pp. 172-194.

[41]Colette A. Daiute, "Physical and Cognitive Factors in Revising: Insights From Studies With Computers," *Research in the Teaching of English,* vol. 20, 1986, pp. 141-159; Colette A. Daiute, *Writing and Computers (Reading,* MA: Addison-Wesley, *1985);* and L. Flower et al., "Detection, Diagnosis, and the Strategies of Revision," College *Composition and Communication,* vol. 37, 1986, pp. 16,55.

because it is rare for beginning writers to revise in this fashion, regardless of their age.[42]

Findings concerning how learning disabled students use the word processor are consistent with those from studies of regular students. In a year-long study, learning disabled students who used the word processor as a supplement to writing instruction made significant gains in their writing ability compared to a control group that did not receive the special intervention.[43] It appears that the word processor alone does not significantly enhance the writing abilities of either regular or learning disabled students. But when coupled with instruction in strategies for writing (for example, strategies for generating ideas or for revising) tend to produce more fluency in writing and revisions that affect meaning.[44]

[42]Colette A. Daiute, "Rewriting, Revising and Recopy ing," paper presented at the meeting of the American Educational Research Association, New Orleans, April 1984; and Colette A. Daiute and John Kruidenier, "A Self-Questioning Strategy To Increase Young Writers' Revising Processes," *Applied Psycholinguistics,* vol. 6, 1985, pp. 307-318.

[43]L.B. Kershner and B.J. Kistinger, "Language Processing/Word Processing: Written Expression, Computers and Learning Disabled Students," *Learning Disability Quarterly,* vol. 7, 1984, pp. 329-335. See also S. Graham and Charles MacArthur, "Improving Learning Disabled Students' Skills at Revising Essays Produced on a Word Processor: Self-Instructional Strategy Training, " unpublished raw data, 1987.

[44]See, for example, Catherine C. Morocco and S.B. Neuman, *Teachers, Children and the Magical Writing Machine* (Newton, MA: E. C. C., 1987); C. Morocco and S.B. Neuman, "Word Processors and the Acquisitions of Writing *Strategies,"Journal of Learning Disabilities,* vol. 19, 1986, pp. 243-247; E. Ellis and E. Sabornie, "Effective Instruction With Microcomputers: Promises, Practices and Preliminary Findings," *Focus on Exceptional Children,* vol. 19, No. 4, 1986, pp. 1-16; Charles A. MacArthur et al., *Learning Disabled Students' Composing With Three Methods: Handwriting, Dictation and Word Processing,* Research Report No. 109 (College Park, MD: University of Maryland, Institute for the Study of Exceptional Children and Youth, 1986); and S.B. Neuman and C. Morocco, *Two Hands is Hard for Me: Keyboarding and Learning Disabled Children* (Newton, MA: University of Lowell, Education Development Center, 1986).

LANGUAGE ARTS

Reading Comprehension

According to reading theory, comprehension is dependent on several cognitive processes, including decoding, word recognition, and knowledge. If a reader is deficient in one or more of these aspects, the ability to read and understand will be impaired. Early instruction in reading typically aims to develop proficiency in the subprocesses, so that learners can devote intellectual activity to higher levels of thinking. While the vast majority of computer-based learning materials treat the simplest of language tasks—spelling and vocabulary—there are some products that aim at more complex aspects of comprehension.

In a study of 108 low-achieving, poor black children, it was found that students who used two reading programs outperformed a control group in both accuracy and efficiency of decoding and recognition.[45] These programs, called *Construct-a-Word* and *Hint-and-Hunt,* have students compose words from letter strings and identify words with vowels and vowel combinations. The improvements for low-ability students were substantial–they gained over 1 year on standardized tests—but students who were already adequate in their decoding skills did not show any changes. The findings were essentially the same for the development of students' ability to comprehend phrases and sentences.

The hypothesis that a computer can enable readers to understand text according to their individual needs for assistance in comprehension has been tested in a controlled experiment; results showed that students who received various forms of comprehension assistance—without asking for such assistance—outperformed other groups.[46] In addition, computers have been paired with speech synthesizers to assist both regular and special education students in understanding words or pairs of words. Among the perceived advantages of computer-aided reading, researchers point out that: 1) disabled readers can conveniently and privately receive the decoding help they need without an indi-

[45]Steven F. Roth and Isabel L. Beck, "Theoretical and Instructional Implications of the Assessment of Two Microcomputer Word Recognition Programs," *Reading Research Quarterly,* vol. 22, 1987, pp. 197-218.

[46]David Reinking and Robert Schreiner, "The Effects of Computer-Mediated Text on Measures of Reading Comprehension and Reading Behavior," *Reading Research Quarterly,* vol. 10, No. 5, 1985, pp. 536-551.

vidual human tutor or teacher, 2) speech feedback can be tailored to match the unique needs of each student, 3) a wider variety of reading materials can be used, 4) reading can become a means for gaining knowledge, 5) the amount of actual time spent reading is maximized because the reader/student does not have to wait for the teacher to explain an unknown word or spend lengthy periods trying to identify difficult words, 6) students are more likely to experience a feeling of success as they progress through the material and easily gain knowledge of new words and increased information from the passages, and 7) the computer maintains a detailed record of the student's reading and requests for assistance, thereby providing researchers with useful information for the study of comprehension problems.[47]

In one study of the impact of computer-aided reading on reading disabled students aged 8 to 18, it was demonstrated that the students enjoyed using the system and showed significant short-term gains in word recognition and comprehension when audio feedback was available.[48]

In another pilot study, six students enrolled in an adult education center were observed individually and interviewed by researchers as they used a computer-aided reading system. The researchers asked the participants to alternate reading the passages with and without the use of the speech feedback. One of the more interesting findings was that use of the speech feedback significantly reduced the level of stress the participants exhibited when struggling with reading in the unaided situation. The participants commented about how hard it was to read and asked if they had to continue. The researchers reported that much of the stress disappeared when they used the speech feedback. The students all indicated that it was much easier to read when they had the assistance and inquired if it were possible to obtain such a system for their personal use and for use by their children or spouses. In addition, many students indicated that they would read more if such a system were available.[49]

Vocabulary and Grammar

Staff at the Houston Independent School District used speech synthesizers in their locally-developed computer courseware designed to assist limited English proficient students in learning English vocabulary and grammar. The district resorted to developing their own computer-based instructional system when they were unable to locate commercially-developed materials suitable for their 34,000 limited English proficient students. The resulting courseware incorporates dynamic, high resolution graphics and digitized speech within a variety of simulation and game programs and is intended for students in kindergarten through fifth grades. Results of one of the 14 courseware units showed that the treatment group scored significantly better than did control students.[50]

Writing, Reading, and Spelling

One of the most widely marketed computer-based educational programs using digitized speech is IBM's *Writing to Read*. It is a multicomponent system involving kindergarten and first grade children in typing words, reading while listening to tape-recorded stories, and listening to computerized speech designed to teach basic phonics.

The evaluation of *Writing to Read* was one of the most comprehensive studies conducted at the kindergarten and first grade levels. A nationwide sample of 35 *Writing to Read* schools and 25 non-*Writing to Read* schools was assessed, representing over 200 teachers and 7,000 children. Writing, reading, and spelling skills were measured.[51]

The results showed that the *Writing to Read* students performed significantly better in writing than

W. 'George W et al., Center for the Study of Reading, University of Illinois, Urbana-Champaign, "Computer Aided Reading With Illiterate Adults," unpublished manuscript, *1987*.

'R. "*Reading* l., "Readin and Remediation Reme the Aid of Computer Speech," *Behavior Research Methods, Instruments and* anc vol. 18, No. 2, 1986, pp. 93-99; and R. Olson and B. Wise, "Computer Speech in Reading Instruction," Instruction and *Reading: R for ng: Issu and Theory D. l Practice* (cd.) einki York, NY: Teachers College Press, 1987).

[49]George V. M David e anc "computer Aided puter adir An Environment for Developmental Research," paper presented at the Society for Research on Child Development, Toronto, Canada, 1985.

the Anderson, *English as a Second Language: d Language Cou. me its u Report* (Houston, TX: Houston Independent School n and 1985).

'lRichard T. Murphy and Lola Rhea id Lola Rhea App *of Eva.iatio Yo to Read Instructional System 1982-84* (Princeton, (F Educational Testing Service, 1984).

the control students in both kindergarten and first grade (table 3-l). *Writing to Read* students in the first grade 1 year after using the program still outperformed non-Writing to Read students, but the differences between the two groups narrowed substantially. In fact, while the non-Writing to *Read* scores increased over the year, the *Writing to Read* **scores** decreased slightly. The effects of the program were consistent across all ethnic groups, with the exception of Oriental students where the non-*Writing to Read* students performed slightly better than the *Writing to Read* students. Classroom observations revealed that students were delighted with their writing and eager to read their passages aloud to visitors.

The results for reading were less impressive. Children in both the *non-Writing to Read* and the *Writing to Read* program progressed at about the same pace.

Table 3-1 .–Mean Writing Scores by Group (percent)

Group	Writing to Read	Non-Writing to Read
Kindergarten	4.5	3.1
First grade	6.6	4.9
First grade after *Writing* to *Read*	*6.5*	*5.7*

SOURCE: Richard T. Murphy and Lola Rhea Appel, ***Evaluation of the*** *Writing* ***to*** *Read instructional System,* **1982-84 (Princeton, NJ: Educational Testing Service, 1984).**

Spelling was assessed in a less systematic fashion, but results showed that the performance of both groups was quite similar: although it uses a phonetic alphabet, *Writing to Read* did not appear to have a negative affect on students' spelling.

Photo credit: IBM

The IBM *Writing to Read* Project has been adopted by many schools as a way of improving early reading and writing skills.

A survey of teachers showed that *Writing to Read* teachers rated the program far more effective for above-average students than for average or below-average students. Unfortunately, the study suffered from a problem found in several other studies described in this chapter—the *Writing to Read* students spent more time in reading instruction than did the control groups.[52] A larger percentage of teachers involved in the *Writing to Read* program reported spending more time on reading instruction than in previous years (58.2 percent) than did the non- *Writing to Read* teachers (26.7 percent). In writing, 80,5 percent of the *Writing to Read* teachers indicated that they spent more time on writing than in the previous years as compared with 30.5 percent in the non-Writing *to Read* classrooms. On the one hand, any program that engages kindergarten and first-grade children in writing activities is desirable, but the positive effects found in the program may be attributable to increased time rather than to any aspect of the *Writing to Read* program.

Researchers at Vanderbilt University's Learning Technology Center have shown that the speech synthesizer can be effective in providing spelling instruction. In traditional approaches to spelling instruction, the teacher says the word, students write it, and then the written word is compared to the correctly spelled word. Some computerized approaches have students type the word from a model on the screen, then type the same word after the model is removed, and then enter the word into a sentence. Most studies using variations on this instructional theme have shown either no significant difference between computer and noncomputer groups and/or limited success with either group.[53]

The Vanderbilt researchers argue that these approaches were unsuccessful because the student could rely on spelling the word by engaging short-term memory. They investigated presenting the spelling words to students by using a voice simulator, which, they believe, activates long-term memory. When the student spells the word incorrectly, the computer visually and auditorially imitates the student's error and provides the correct spelling, so that the student can compare the two, Results of studies using this approach show that computer-using students achieved an accuracy of over 90 percent on lists of spelling words; in addition, the computer students averaged over 30 percent more correctly spelled words than when they used traditional procedures.[54]

[52] Olson and Wise, op. cit., footnote 48.

[53] G. Fitzgerald et al., "Computer-Assisted Instruction for Students with Attentional Difficulties," *Journal of Learning Disabilities*, vol. 19, *No. 6, 1986*, pp. 376-379; P.A. McDermott and M.W. Watkins, "Computerized vs. Conventional Remedial Instruction for Learning-Disabled Pupils," *Journal of Special Education, vol. 1, No. 1,* 1983; Jacqueline Haynes et al., *Effect of Computer-Assisted Instruction on Learning Disabled Readers' Metacognition and Learning of New Words*, Research Report No. 101 (College Park, MD: University of Maryland, Institute for the Study of Exceptional Children and Youth, 1984).

[54] Ted Hasselbring, "Remediating Spelling Problems in Learning-Handicapped Students Through the Use of Microcomputers,)' *Educational Technology*, *vol.* 22, 1982, pp. 31-32; and Ted Hasselbring, "Using a Microcomputer for Imitating Student Errors to Improve Spelling Performance, "*Computers, Reading and Language Arts,* vol. 4, 1984, pp. 12-14. See also Ted Hasselbring, "Effective Computer Use in Special Education: What Does the Research Tell Us?" a paper presented at Funder Forum, sponsored by Apple Computer, Inc., Cupertino, CA, 1987.

ELECTRONIC NETWORKS

Electronic networks allow individuals or groups to communicate with one another using computers that are connected through local area networks (LANs) or through telephone lines. Electronic networks are being used in every subject area and at all but the earliest grade levels. A good example of a computer network used in education is the Computer Chronicles Newswire project, where third and fourth grade students in Alaska communicate with students in California about events and issues in their school and community. Each site publishes a newspaper that consists of articles selected by the student editorial board. Through this process, students engaged in dialogs with others from a different culture, struggled with communicating clearly in writing, and gained valuable experience in evaluating and revising compositions.[55] Similarly, in a computer network called De Orilla a Orilla (From Shore to Shore), limited and non-English speaking students in New England and California are paired

[55] M.M. Riel, "The Computer Chronicles Newswire: A Functional Learning Environment for Acquiring Literacy *Skills,* "*Journal of Educational Computing Research*, vol. 1, 1985, pp. 317-337.

with Spanish-speaking students in Mexico and Puerto Rico for the purpose of improving their writing skills.[56] Another international computer communications network involves students in eight secondary and college groups in the United States, Japan, and Israel. The project is designed to permit students from different cultures to use one another as resources for learning about their social, cultural, and physical worlds. Participating students explore topics such as peaceful alternatives to war, how schools prepare students for careers, peer violence, and water supply systems.[57]

Children in fourth through sixth grades are now collecting, recording, and comparing the range of acidity or alkalinity of common liquids, including rain, using an electronic network established through a joint venture among the Technical Education Research Centers, the National Geographic Society, and the National Science Foundation.

This National Geographic Kids Network allows students to share information they collect with each other and a specially designated scientist on topics such as weather forecasting, water pollution, and food growing. A powerful central computer is used to summarize data supplied by the students and to create charts, maps, and other presentations which are sent back to the students. In their classrooms, students then analyze patterns and trends in their data and compare their results with children in other schools across the Nation. Results from a pilot study of this network's first year of operation were very promising.[58]

Another science project using electronic communications was tested by sixth-grade students and teachers in New York City.[59] This project, called Earth Lab, allowed students to collect, analyze,

Photo credit: Steve Raymer, National Geographic Society

In the Kids Network Project, students collect water for PH testing as a part of the acid rain unit.

Photo credit: Cecilia Lenk, Technical Education Resource Centers

Mapping activities are important as students compare their data with that of other student scientists on the Network.

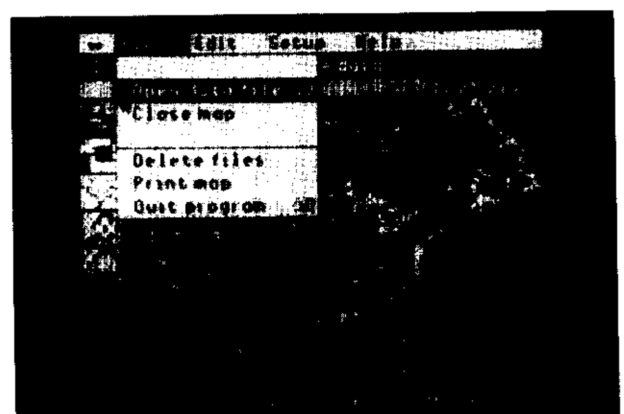


Photo credit: Sara Witherow, Technical Education Resource Centers

The mapping software is used to find the "global address," or latitude and longitude, of any place on the map, to zoom-in on areas for details, and to overlay Network data on the map.

[56] According to Sayers and Brown, initiators of the project, "Students in bilingual education programs need authentic contexts for mother-tongue writing if they are to develop and maintain basic literacy skills and then transfer them to English academic settings." Sayers considers computer networks to be a "perfect fit" with the special needs of bilingual students. See Dennis Sayers and K. Brown, "Bilingual Education, Second Language Learning and Telecommunication: A Perfect Fit," *CALL Digest,* vol. 3, No. 5, 1987; and Dennis Sayers, "Bilingual Sister Classes in Computer Writing Networks," unpublished manuscript, 1987.

[57] M.M. Riel, "Intercultural Learning Network," CALL *Digest,* vol. 3, No. 5, 1987.

[58] See Technical Education Research Centers, Cambridge, MA, "National Geographic Society Kids Network Project Annual Report, October 1, 1986-September 30, 1987."

[59] David Newman et al., *Earth Lab: Progress Report* (New York, NY: Bank Street College of Education, 1987).

share, and write about their own science research projects on geographic systems, such as convection, the water cycle, and weather forecasting. Earth Lab was designed for teachers who have little or no prior experience with computers or the complexities of real world science,

Teachers in remote rural areas are using electronic networks to discuss the issues and problems they face in teaching science. The Educational Technology Center at Harvard University has organized and is studying a network designed to encourage teachers to pose and respond to each other's questions about science instruction and to participate in discussions originated by "guest" scientists and educators. Early results indicate that more isolated teachers use the network more frequently, and that all teachers found the information obtained through the network valuable.

CONCLUSIONS

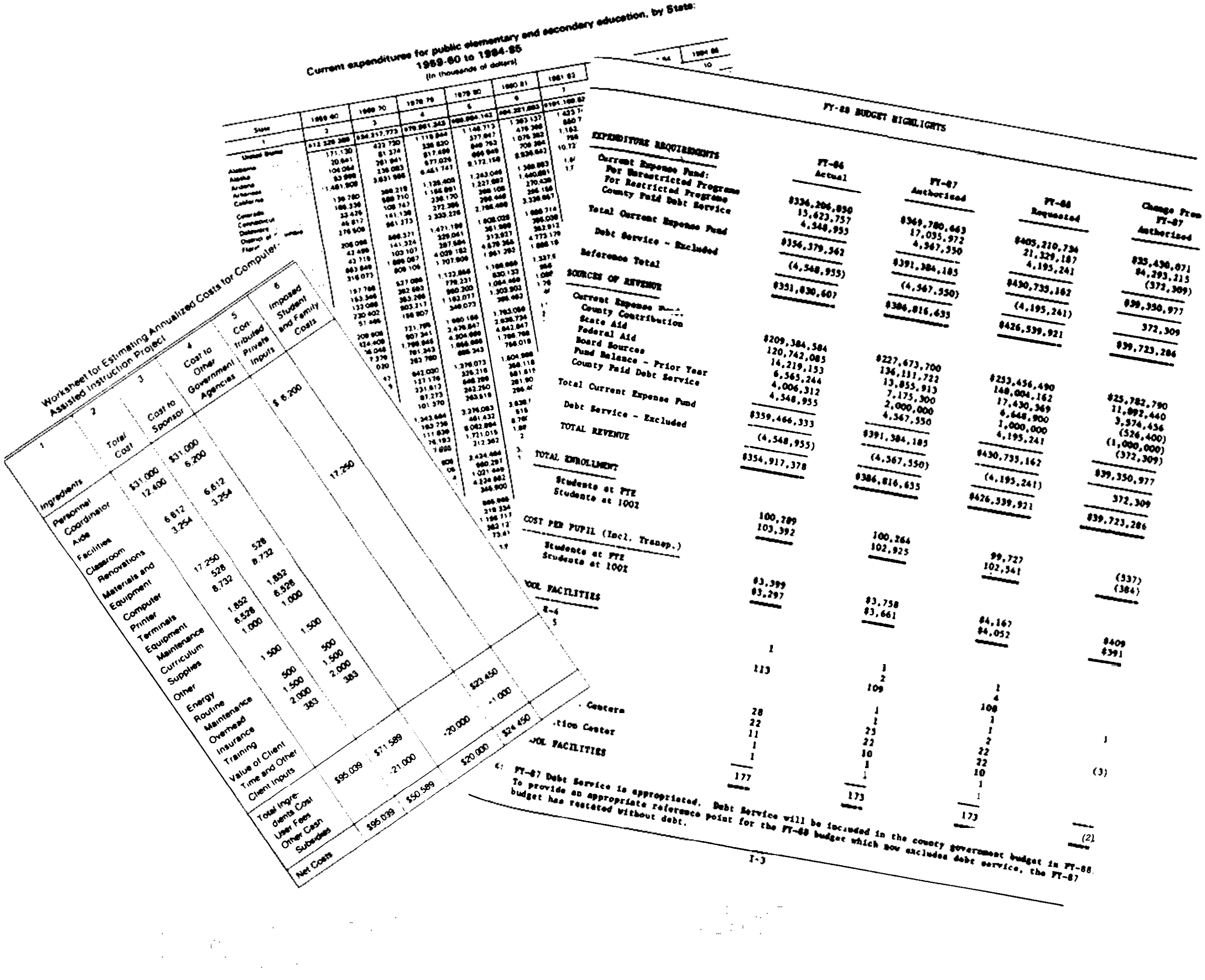
The "natural experiment" with interactive technologies that began in American schools 30 years ago has spawned a new and growing family of research and evaluation studies, which have already borne a substantial harvest of results and hypotheses that warrant ongoing investigation. While in the early days the focus was almost exclusively on mainframe and minicomputer CAI systems, today's research agenda spans a much wider spectrum of technologies and explores their effects on the full array of educational processes. As important, the advent of interactive educational technologies has stimulated and facilitated new research forays into the cognitive workings of the human mind: *technologies for learning* are helping us to understand the *technology of learning.* It is hoped that this new knowledge will eventually translate to products and processes that can expand conventional limits to human information processing.

OTA recognizes that research in this complex field of education yields findings that may be divergent or ambiguous. It should be remembered that many of the research models that map relationships between inputs and educational productivity have been imported from the worlds of science and business, where it is easier to define outcomes and identify the production technology. Ironically, while business firms might have opted for a rigorous experimental approach to office automation, using familiar indicators such as profits and losses to determine optimal technologies, they chose instead a strategy of *learning--by-doing:* hardware and software were installed and experience dictated the direction of change and improvement. While it is true that schools do not enjoy the decisionmaking and resource allocation flexibility of business firms, it is also true that the effective integration of new technologies will require an atmosphere of openness to trial, error, and correction.

The analogy with business and industry is instructive for another reason. Perhaps the single most important distinction between these sectors' involvement with interactive technology is their mode of financing and governance. Education is a public enterprise funded at the State and local level, and resource allocation is necessarily highly politicized. Unlike business firms which, in theory at least, learn about the efficiency of their operations from the market, and which enjoy considerable latitude in adjusting to new technologies and new market forces, schools operate in an environment where inefficiencies are neither obvious nor easily remedied. The paradox is that while the exigencies of school budgeting and governance heighten the need for careful planning and efficient utilization of scarce resources, the complexities of education pose significant limitations to the application of simple efficiency criteria. It is not by simple oversight that virtually all of the studies cited in this chapter omitted consideration of the *costs* of the technologies in question. Nevertheless, while educators and other users of these technologies may be concerned primarily with their effects on children's school experiences, policymakers are facing growing pressure to demonstrate that those benefits justify their costs. In an era when performance, productivity, and efficiency of our educational institutions are priority issues, it is inevitable that the cost-effectiveness of new technologies should be questioned. This subject is addressed in the next chapter.

Chapter 4

Cost-Effectiveness: Dollars and Sense



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INTRODUCTION AND FINDINGS

How much do new instructional technologies cost? Are they worth the investment? These are not academic questions, but have important practical consequences. "Buy more hardware" sounds appealing, especially to advocates of computer-based instruction, until someone points out that the additional equipment is likely to come at the expense of other materials or programs. Difficult questions inevitably follow: Will the new learning tools be more effective than books? Could reductions in class size bring about similar achievement gains at lower cost? Should a school district invest in an integrated learning system (ILS) or in another form of computer-based instruction? Will computer-based materials bring about savings on traditional instructional materials?

These questions are not easily answered, in part because of obstacles to definition and measurement of the costs of various technological alternatives. Most experts acknowledge that simply installing computers in classrooms will not be effective without good software, well-trained teachers, reliable systems maintenance, and planning how the technology will be used. **Assessing the costs, therefore, involves considerably more than the price and quantity of equipment. In many school districts, detailed administrative data are not available, and important economic considerations such as depreciation of capital equipment and the opportunity costs of new technologies are neglected.**

The fundamental problem, however, lies on the effects side of the equation. Short-term and long-term effects of employing educational technologies are different and not necessarily consistent. For instance, evidence that computer-assisted instruction (CAI) can be a cost-effective method to raise achievement test scores in the short run is an important finding. For many educators, however, the appeal of the computer is based on the hope that it will eventually liberate them and their students from rote drill, and push the traditional frontiers of human learning.[1] In addition, the cost-effectiveness of a given educational technology can vary significantly with the specific characteristics of schools and students. A successful program in one location may be less successful elsewhere.

Without evidence of short-run gains, teachers, administrators, parents, and students might lose faith in the grander vision, making it difficult to garner the necessary political and financial resources to support continued research and development of the newest learning tools. But if short-run effects and cost-effectiveness are overemphasized, researchers and practitioners may lose sight of the longer-term potential, and future historians will lament the missed opportunities for changing the way children learn.

This chapter begins with an estimate of the costs of several approaches to using computers in classroom instruction. **OTA finds that the current national average of 1 computer per 30 public school children represents an insignificant fraction of total annual educational expenditures. However, substantial expansion could require a commitment of nearly one-third the current annual outlay on nonpersonnel instructional resources.** (Because OTA has found no evidence that computers and related technologies have displaced teachers, it is important to assume that salaries and benefits will remain at the current percentage of the total; if anything, salaries may rise.)

The chapter then addresses the problem of linking costs to anticipated effects. OTA finds that cost-effectiveness comparisons of alternative policies, which show expected gains per dollar of expend.

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[1] Others, however, are fearful that the technologies will dictate inappropriate teaching methods: "If you begin with a device of any kind, you will try to develop the teaching program to fit that device." T. Gilbert, "On the Relevance of Laboratory Investigation of Learning to Self-Instructional Programming," *Teaching Machines and Programmed Learning: A Source Book*, A.A. Lumsdaine and R. Glaser (eds.) (Washington, DC: National Education Association, 1960).

iture, can be a useful decisionmaking criterion. For example, based on a review of several cost-effectiveness studies, OTA finds that:

- CAI can be more cost-effective than certain other nontechnological methods of achieving similar educational objectives, among particular groups of students;
- some forms of CAI are more cost-effective than others;
- the cost-effectiveness of learning technologies is very sensitive to particular characteristics of schools and classrooms where they are implemented;
- there is much research that addresses costs *or* effects of computer-based instruction separately, but there is a need for more work that considers these issues together;
- with better data and access to appropriate analytical tools, cost-effectiveness could become a more widely used and informative decisionmaking criterion; and
- 6 the Federal Government could provide assistance in data collection and research design for cost-effectiveness analysis and dissemination of results.

ESTIMATING THE COSTS OF ALTERNATIVE INSTRUCTIONAL TECHNOLOGIES

An Illustrative Case

As described in chapter 6, a networked ILS provides instruction in large portions of the curriculum and computerized student monitoring, testing, and reporting. These systems are typically sold as hardware-software bundles, in some cases with dedicated computers but more often with standard computers for student work stations. Some ILS manufacturers offer their software for the Apple, IBM, and Tandy computers, while others develop materials solely for one brand.

The ILS market is competitive, with at least a dozen manufacturers offering systems that vary in scope, breadth, and cost. Some ILSs consist of software that is strictly drill-and-practice, while others are instructional delivery systems that teach new material, including simulations and tools, and allow children to advance through curricula at their own pace. Because system requirements can vary widely by curriculum as well as by the number of children (or classrooms) served, the average cost of installed integrated systems nationwide is not a particularly informative statistic. It may be more useful to illustrate the costs involved by examining a specific case.

The instructional delivery system recently chosen by Prince George's County (Maryland) will provide CAI in mathematics, reading, and language arts to second and third graders in 68 elementary schools. Assuming an average class size of about 26, the system will be utilized by about 9,000 children in 349 classes.[2] Each classroom will have four IBM PS/2 Model 25 computers, equipped with 640K RAM (kilobytes of random access memory), two 800K 3 1/2" floppy disc drives, a mouse, speech adapter, and earphone/microphone. Each classroom will also

*Photo credit: Michael **Feuer**, OTA staff*

At the Martin Luther King, Jr. School in Washington, DC, an integrated learning system provides individualized student pacing, monitoring, and testing across large portions of the school curriculum. Each student can beat work on a different topic and skill level, as reports produced for the teacher highlight areas needing further classroom instruction.

[2] The average class size reported in county data is 25.7. See Prince George's County Public Schools, Office of Pupil Accounting and School Boundaries, "Class Size Report, 1987-1988 School Year," unpublished manuscript, 1987.

have one IBM Proprinter. The classroom computers will be connected via local area network in each school to an IBM PS/2 Model 60 host computer, with approximately 2 megabytes RAM and a 40 megabyte hard disc, as well as a Sony CD-ROM (compact disc-read only memory) player. The hard disc will hold the school's student records and test results, and the instructional software will be housed on the optical storage device.

The instructional software for this system, produced by Education Systems Corp. (ESC), consists of about 2,000 programs, each with approximately 250-300K of memory, with full color and graphics. Each of these programs delivers about 15 minutes of instruction, depending on students' abilities. In a typical half-hour session, most children complete two lessons, though not necessarily on the same topic. The management system monitors individual student progress and prepares reports for teachers and staff.

The purchase price for the whole system, to be operational in the fall of 1988, is $5.1 million,[3] and will be paid off over 5 years. (As is commonly the case, the county will enter a leasing arrangement with a third party lender.) This total cost breaks down roughly to $2 million in software and $3 million in hardware, including the first year of hardware and software maintenance as well as the first year of training. For the second through fifth years, there are additional charges: the county will contract with a local vendor for hardware maintenance, and will pay ESC about $220,000 per year for software upgrades, new materials, and ongoing teacher training. Not counting other indirect costs, such as salary and benefits of personnel and teacher time away from the classroom during training, and not counting the annual hardware maintenance contract, the true annual cost to the county will be approximately $1.5 million.[4] Adding the costs of rewiring the classrooms, electrical service modifications, and building and facilities depreciation, the annual cost climbs to at least $1.8 million. This translates to over $26,000 per school.

[3]Competing bids ranged from $4 million to $9 million.

[4]This figure is derived using an annualization factor that assumes a 10 percent interest rate. See Henry Levin, Cost *Effectiveness: A* Primer (Beverly Hills, CA: Sage Publications, 1983), p. 70.

This is a small portion (0.4 percent) of the $430.7 million total projected fiscal year 1988 Prince George's County public school budget. However, this computer system affects only 68 of the 108 elementary schools (in a system of 173 schools), and it is going into second and third grade classes only. If the same type of system were installed in grades 2 and 3 in all 108 elementary schools, then by simple extrapolation it would cost about $2.9 million per year (about $26,000 per school), which would represent 1.4 percent of the total annual expenditures on elementary schools, or 0.7 percent of the total 1988 budget. Extrapolating further, it would cost about $10 million annually for a system that reached all the elementary school children in grades K-6 (close to $95,000 per school), or 4.8 percent of the elementary school budget and 2.4 percent of the total school district budget.[5] These estimates are displayed in table 4-1.

Even the most expensive scenario depicted in table 4-1 appears to take a relatively small fraction of the total county budget. But 63 percent of that total budget is accounted for by salaries and fringe benefits of instructional staff. The estimated annual cost of $1.8 million to install the ESC/IBM system (in grades 2 and 3 in 68 schools) represents close to 11 percent of the approved budget for instructional materials, exclusive of instructional salaries. (See figure 4-1.)

The Cost to the Nation: Two Scenarios

Many educational technologists would prefer to see schools with both ILS laboratories and classrooms equipped with free-standing computers. For illustration, then, OTA has estimated the costs of an ILS laboratory plus five stand-alone computers per class in a school with 20 classrooms. In this scenario, the classroom ratio would improve from the current national average of about 1 computer for 30 children to 1 computer for 6 children; raising the inventory in this fashion could substantially improve the access to computer learning tools.

To cost out this scenario, assume that the ILS laboratory consists of 30 student work stations, each equipped with a computer of the speed and capac-

[5]Estimates are based on a simple linear extrapolation and do not necessarily reflect additional potential volume discounts.

Table 4.1.—Costs of an Integrated Learning System[a] for Elementary Schools in Prince George's County, Maryland

	Number of schools	Grade levels (number of pupils[b])	Estimated annual cost (millions)	Percent of elementary school budget ($214.7 million)[b]	Percent of district budget ($430.7 million)	Percent of instructional costs[c] ($16.6 million)
Approved plan, effective fall	68	2-3 (8,970)	$1.8	0.84	0.42	10.8
OTA extrapolations (estimated date)	68	K-6 (33,370)	4,0	1.86	0.93	24,1
	108	2-3 (15,140)	2.9	1.35	0.67	17.5
	108	K-6 (53,000)	10.2	4.75	2.37	61.4

[a]Education Systems Corp. software and IBM hardware. See text for specifications.
[b]Approximate.
[c]Excluding teacher salaries and benefits.

SOURCE: Board of Education of Prince George's County, Maryland, "Annual Operating Budget, July 1, 1987 to June 30, 1988;" and Board of Education of Prince George's County, Maryland, "Board Action Summary: Introduction of Computer Assisted Instruction, Grades Two and Three," Jan. 28, 1988.

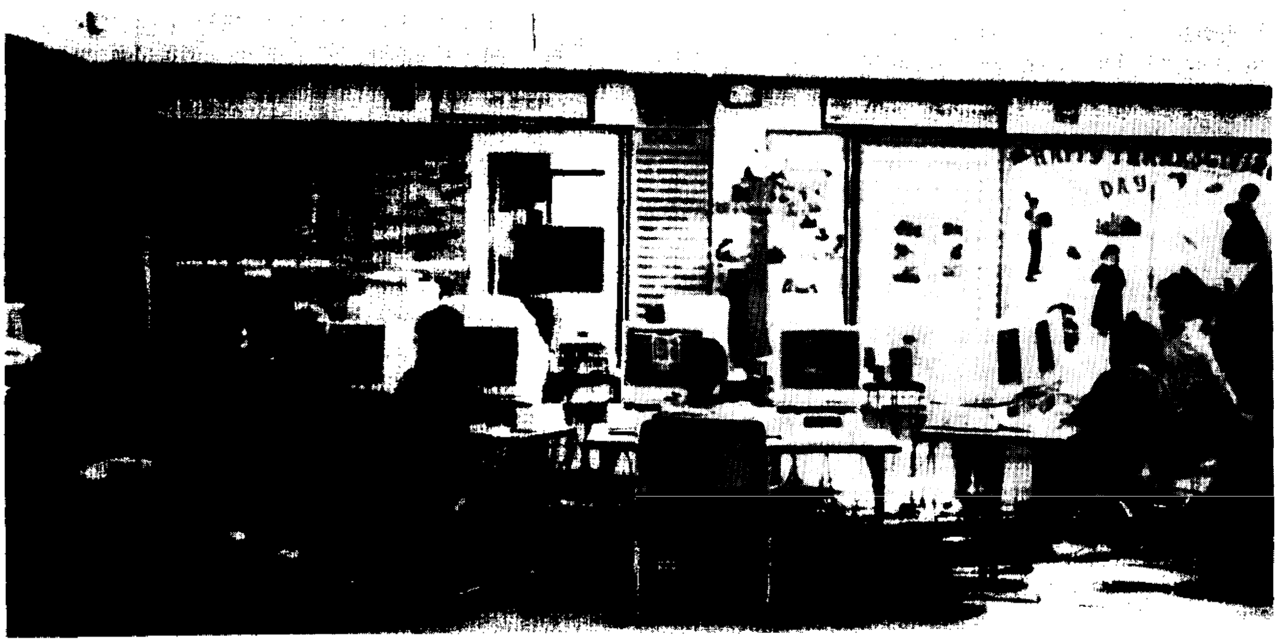


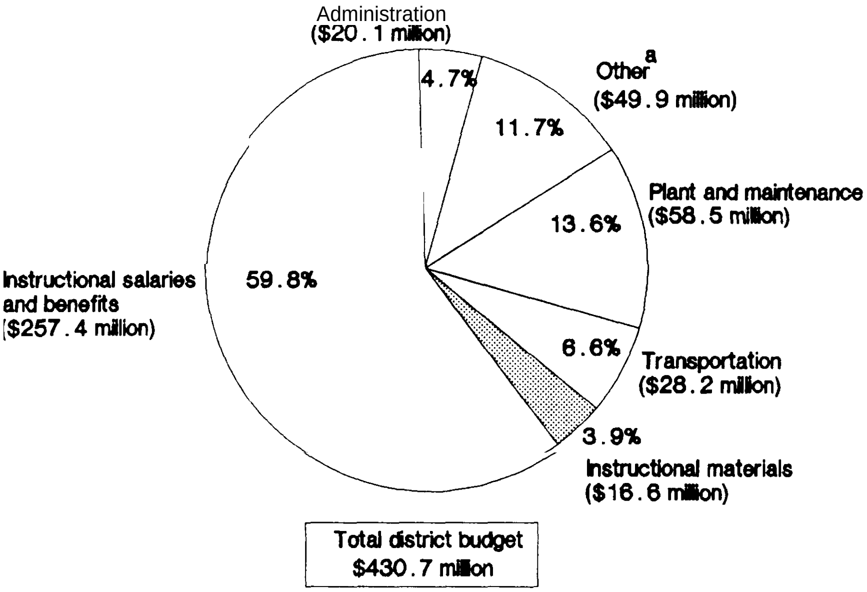
Photo credit: ***Massachusetts Institute of Technology***

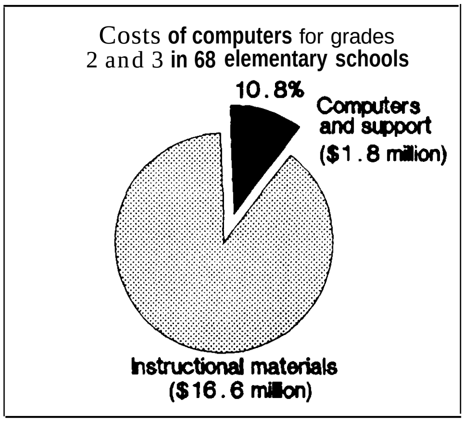
This technology-rich environment at the Hennigan School in Boston is supported by industry, local school funds, and university research grants. What would it cost to set up learning environments like this "around the country?

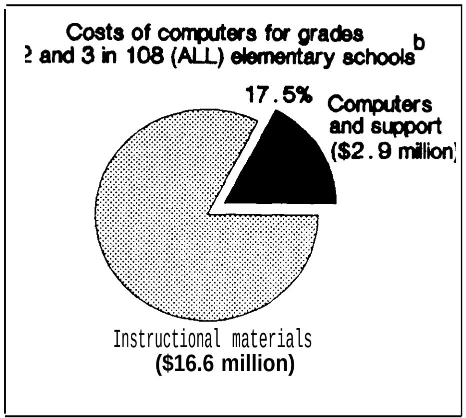
ity of the Apple II-GS or IBM PS/2 Model 25, plus networking and speech hardware. The cost of each work station is approximately $1,500. In addition, the laboratory would have a central file server (a computer with the speed and capacity of the IBM-AT), CD-ROM, and printer, at an estimated cost of $5,000. Integrated software such as the type installed in the Prince George's County elementary schools would cost about $60,000, bringing the total cost of the laboratory to about $110,000.

The five free-standing computers installed in each of the 20 classrooms would cost approximately $100,000, and software at $5 per pupil would cost about $3,000. The total cost to the school for this combined laboratory and free-standing classroom computer installation, excluding physical renovations, electric wiring, annual maintenance, and training charges, would approach $215,000. For a large school district like Chicago, with about 600 schools, the total cost would be at least $130 mil-

Figure 4-1.—District Education Budget and Costs of Implementing a Computer= Based Integrated Learning System (ILS) in Prince George's County, MD







[a]Includes pupil personnel services and health services.
[b]OTA estimates based on extrapolations of costs in 68 schools,

SOURCE: Office of Technology Assessment based on the Board of Education of Prince George's County, MD, "Annual Operating Budget, July 1, 1967 to June 30, 1966, "

lion, or roughly $30 million per year (assuming a 6-year time horizon and 10 percent interest rate). For a small district with only five schools, the annual cost would be approximately $250,000. (Note that these estimates do not account for the current installed base of computers.)

Finally, OTA has explored the cost implications of a rapid and even more dramatic expansion. To simplify this illustration, assume a current installed base of 1.3 million computers. Increasing this inventory by 12 million computers would change the computer: student ratio from 1:30 to 1:3, an aspiration often cited by school district personnel and educational technologists. (These estimates are presented solely for illustrative purposes, and do not necessarily reflect OTA's belief in the feasibility or desirability of implementing a program of this magnitude.)

As shown in table 4-2, to purchase 12 million additional computers plus an adequate number of printers would cost nearly $14 billion.[6] The annualized cost of hardware, assuming a 6-year lifetime and an interest rate of 10 percent, would amount to $3.17 billion. Software, maintenance, equipment upgrades, and teacher training are all critical additional expenses, estimated at roughly $990 million per year, bringing the total annual cost to over $4 billion.[7]

This figure is but a tiny fraction of the gross national product (over $4 trillion), and a seemingly insignificant 3 percent of total U.S. expenditures on public elementary and secondary schools. However,

Table 4-2.—Approximate Cost of Major Expansion of Installed Base of Free-Standing Computers in U.S. Public Elementary and Secondary Schools

	cost (in millions)	
Hardware[a]		
12 million computers @ $1,000 each .	$12,000	
5 million printers @ $400 each	2,000	
Total	$14,000	
Annualized cost, assuming 6-year equipment life and 10% interest rate		$3,200
Other annual costs		
Software @ $5/student	$200	
Maintenance and upgrades cost	700	
Teacher training[b]	100	
Total (non-capital annual).	$1,000	$1,000
Total estimated annual cost.		$4,200

[a]Does not include other peripherals, mass storage devices, or networking.
[b]Assuming 50 percent of all teachers trained annually.

SOURCE: Office of Technology Assessment, 1988

of the $137 billion currently spent on public education, about $85 billion is budgeted for instruction, of which instructional salaries and benefits account for at least 85 percent. OTA has no evidence that computer technologies have displaced teachers; it is important to consider the budget implications of the new learning tools holding personnel costs constant. As shown in figure 4-2, the $4.2 billion annual cost for this massive infusion of new equipment would represent more than 30 percent of the amount currently spent nationwide on instructional materials.

[6]The current New York State contract price is $1,017 for the IBM PS/2 model 25; printers are in the range of $350 to $479. Note that some experts would find the $1,000 estimate low, considering the added costs of a second disc drive, mouse, and networking. Some educators, however, question the utility of these added features. Assistance in generating these estimates was provided by Jim Brewington, Education Systems Corp.; Irwin Kaufman, New York City Board of Education; and LeRoy Finkel, San Mateo County Office of Education.

[7]It might be more realistic to calculate the costs for a gradual phasing-in of these machines, e.g., over 5 or 10 years. Clearly this strategy would be less costly on an annual basis, and would appear more feasible from an implementation standpoint. However, it is important to note that the benefits would have to be discounted accordingly.

COST-EFFECTIVENESS [8]

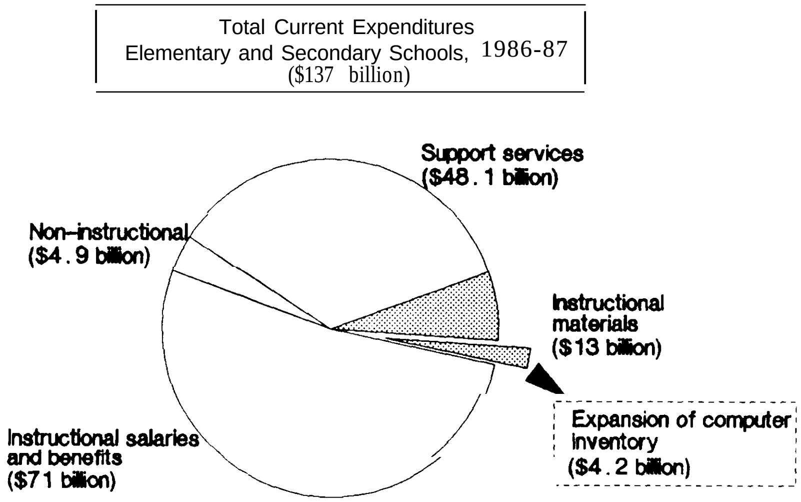
Political and Methodological Considerations

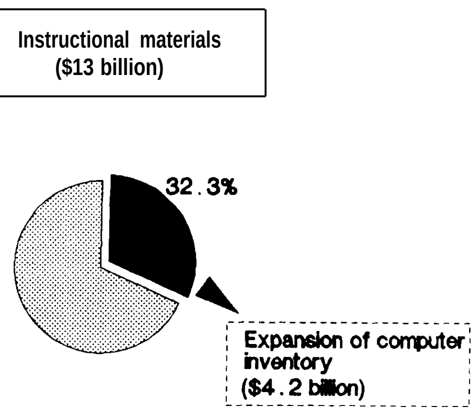
There are always plenty of proposals for improving education. Recommendations for raising teachers' salaries, reducing class size, changing the curriculum, instituting peer tutoring, lengthening the school day, and promoting the use of new learning technologies all have merit. But most school systems cannot afford everything at once. Education is primarily a local function that competes with other projects for a share of the public budget, and school officials are often pressured to demonstrate that the dollars allocated to education are wisely spent.

It is tempting to look at estimates of the costs of computer-based instruction as a fraction of the gross national product or of total education expenditures, and conclude that it would represent a relatively small public commitment. But as mentioned in the introduction to this chapter, even small sums are scrutinized by public officials who must weigh the anticipated benefits of many competing programs. More important, if one considers these costs as a proportion of instructional materials expenditures,

[8]The remainder of this chapter draws heavily on David Stern and Guy Cox, "Assessing Cost Effectiveness of Computer-Based Technology in Public Elementary and Secondary Schools," OTA contractor report, Jan. 8, 1987.

Figure 4-2.— Increasing Computer Inventories in U.S. Public Schools: Projected Impact on Total Annual Instructional Materials Expenditures





SOURCE: Office of Technology Assessment based on U.S. Department of Education, *Digest of Education Statistics, 1987* (Washington, DC: May 1987); and U.S. Department of Education, *Public Elementary and Secondary School Revenues and Current Expenditures for Fiscal Year 1986* (Washington, DC: March 1988).

exclusive of personnel and administration, it becomes clear why policy makers and legislators must view the new technologies in terms of implicit tradeoffs with other learning strategies. Installing integrated systems or stand-alone computers that produce no appreciable gains in achievement, or that cost much more than other options that would produce similar gains, can undermine the credibility of **the decisionmakers as well as the chances for further investment in new technologies as they become available.**

There are several barriers to the implementation and interpretation of cost-effectiveness analysis of educational technology. **Most school districts do not have the resources to devote to the collection of complete cost data, or to the controlled measurement of educational effects.** These are costly undertakings. Where such studies have been done, the choice of outcome and cost measures has been governed largely by the availability of data, rather than by well-defined and testable hypotheses. Differences in results across schools and school districts, therefore, are not easily interpreted. In addition, when cost-effectiveness is measured correctly, it is only with respect to specific outcomes; there is a tendency, however, to interpret results more globally, and to reach conclusions about all computer learning technologies or about a specific one in all schools. As with much educational research, even when outcomes are clearly defined and when commensurable data are employed, findings from one school or group of schools are not necessarily robust, because of important idiosyncrasies of classrooms that cannot be captured by available quantitative data.[9]

Basic Principles of Cost-Effectiveness Analysis[10]

A rationale for using cost-effectiveness analysis is that it allows decisionmakers to select those activities that provide the best educational results for any given costs, or that provide any given level of educational results for the least cost. As mentioned earlier, costs and effects are usually treated independently. Cost-effectiveness analysis, on the other hand, takes into account both aspects in evaluating alternative approaches to obtaining similar goals. It is assumed that 1) only programs with similar or identical goals can be compared, and 2) a common measure of effectiveness can be used to assess them.

Estimation of Costs.–Cost analysis cannot place primary reliance on budget documents for several reasons:

- budgets do not always include all relevant cost information;
- budgets do not necessarily account for resources that have already been paid for;
- standard budget practices may distort the true costs of resources;
- costs of interventions are often embedded in budgets that cover much larger units of operation; and
- most budgets represent plans for how resources will be allocated rather than a classification of expenditures after they have taken place.

For these reasons, the "ingredients method" is recommended. This involves the identification and specification of all the relevant inputs and which requires complete familiarity with the intervention being evaluated. A typical breakdown of ingredients would begin with personnel, facilities, equipment and materials, and client inputs; further refinements would follow. This rigorous method of analysis is time-consuming and costly.

Effectiveness Measures.–Cost-effectiveness analysts must determine the program objective and an appropriate measure of effectiveness, as suggested in table 4-3. Given the cost information for each alternative, the cost and effectiveness data can be combined into cost-effectiveness ratios that show the amount of effectiveness that can be obtained for an estimated cost.

Computer-Assisted Instruction: A Survey of Cost-Effectiveness Research

Economists have attempted to measure the effectiveness of alternative instructional strategies per dollar of cost. An early study dealt with CAI as a method of compensatory education for disadvantaged children.[11] The study found that CAI produced statistically significant gains in achievement, and the per-pupil cost of CAI was found to be well within the per-pupil budget available for compensatory education. The authors concluded that CAI was both feasible and cost effective.

A more recent study combined correlational, experimental, and quasi-experimental findings in order to compare the cost-effectiveness of four different educational policies: reducing class size, lengthening the school day, introducing CAI, and instituting cross-age tutoring.[12] The results show that CAI

[9]See Richard Murnane and Richard Nelson, "Production and Innovation When Techniques are Tacit: The Case of Education," *Journal of Economic Behavior and Organization, vol. 5, 1984,* pp. 353-373.

[10]This section is drawn from Levin, Op. cit., footnote 4.

[11]Dean Jamison et al., "Cost and Performance of Computer-Assisted Instruction for Education of Disadvantaged Children," *Education as an Industry*, J. Froomkin et al. (eds.) (Cambridge, MA: Ballinger, 1976).

[12]Henry Levin et al., "Cost Effectiveness of Four Educational Interventions," IFG Report No. 84-Al 1, Stanford University, 1984. See also Henry Levin and Gail Meister, "Is CAI Cost-Effective?" *Phi Delta Kappan, vol. 67, No. 10, 1986.*

Table 4.3.—Examples of Effectiveness Measures Used in Cost-Effectiveness Analysis

Program objective	Measure of effectiveness
Program completions	Number of students completing program
Reducing dropouts	Number of potential dropouts who graduate
Employment of graduates	Number of graduates placed in appropriate jobs
Student learning	Test scores in appropriate domains utilizing appropriate test instruments
Student satisfaction	Student assessment of program on appropriate instrument to measure satisfaction
Physical performance	Evaluation of student physical condition and physical skills
College placement	Number of students placed in colleges of particular types
Advance college placement	Number of courses and units received by students in advance placement, by subject

SOURCE: Henry Levin, Cost Effectiveness" *A Primer* (Beverly Hills, CA: Sage Publications, 1963), p. 115.

was cost-effective at the elementary level compared to increasing instructional time, but that reducing class size appeared to be more cost-effective than CAI in mathematics. Peer tutoring was the most cost-effective of the four interventions, in both mathematics and reading (see table 4-4).[13]

In an important extension to this work, cost effectiveness was applied to the choice *among* alternative approaches to CAI.[14] This study found that even ILSs, which are self-contained, highly structured, and ostensibly "teacher-proof," yield significantly different effects in different places. The costs of implementation as well as learning effects varied widely among the schools investigated. In addition, the study showed that cost-effectiveness is in part a function of the level of utilization of a given computer-based instructional system. It is often the case that the actual level of utilization is below full capacity, which can be explained in part because educators know that CAI is effective only for some students in the school.[15] Cost-effectiveness is improved when computers are used to full capacity, even though this can entail additional personnel costs to accommodate a full day program. **This line of research is important because it shifts the discussion from whether or not to use computers to the more relevant question: how to assign and implement the appropriate interactive technology to particular school circumstances.**

Other researchers have done cost-effectiveness studies of industrial and military training using computers. Training and education differ fundamentally with respect to the degree of specificity of skills that are taught and with respect to the average age of students. In addition, in the military (as well as in many industrial environments), the main efficiency problem is how to accomplish training objectives in less *time,* which is not the central concern in elementary and secondary schools. Nonetheless, insights can be gained from studies of training.

An expert on the cost-effectiveness of CAI in the military suggests that training and education may be different sides of the same cost-effectiveness coin:

> Trainers are most likely to be interested in minimizing costs to achieve definable thresholds of performance [and] are interested in how much it costs

[13] See also R. Niemiec et al., "CAI Can be Double Effective," *Phi Delta Kappan*, vol. 67, *No.* 10, *1986,* and the rejoinder by Henry Levin et al., *Phi Delta Kappan*, vol. 68, No. 1, 1986.

[14] Henry Levin et al., Stanford University, Center for Educational Research at Stanford, "Cost Effectiveness of Alternative Approaches to Computer-Assisted Instruction," monograph, November 1986.

[15] According to 1985 survey data compiled by Henry Becker, The Johns Hopkins University, Center for Social Organization of Schools, the average percentage of unutilized computer terminals ranged from 2.3 in high schools to 4.5 in elementary schools. There was considerable variance by geographic region and size of community.

Table 4-4.—Cost.Effectiveness of Four Educational Interventions

Intervention	Effects[a] Mathematics	Reading
Computer-assisted instruction	1.0	1.9
Cross-age tutoring		
Peer component	4.6	2.2
Adult component	0.8	0.5
Increasing instructional time	0.5	1.2
Reducing class size		
From To		
35 30	1.4	0.7
30 25	1.2	0.6
25 20	1.0	0.5
35 20	1.1	0.6

[a] In months of additional achievement gain per year of instruction, for each $100 per student. For example: computer-assisted instruction (CAI) yielded an average of 1.9 months of achievement gain, while peer tutoring produced 2.2 months of additional achievement gain, per $100 of instructional cost per student. This difference is slight, and is explained by the substantially higher costs associated with cross-age tutoring than with CA I

SOURCE: Henry Levin and Gail Meister, "IS CA I Cost-Effective?" *Phi Delta Kappan,* VOI 67, No, 10, 1966, p 748.

to achieve a unit of effectiveness, or, in the ratio of cost to effectiveness; educators . . . usually work with fixed costs to maximize performance and are likely to be interested in how much effectiveness they get for a unit of cost, i.e., the ratio of effectiveness to cost. 'b

From research conducted at the Institute for Defense Analyses on the relative cost-effectiveness of computer-based v. traditional training, preliminary results show that:

- **CAI costs about one-third less per unit of effectiveness than conventional instruction;**
- **computer-managed instruction** (CMI) costs about one-quarter less per unit of effectiveness than conventional instruction;
- CAI costs about 10 percent less than CMI per unit of effectiveness;
- computer-based instruction, or CAI and CMI combined, costs about 30 percent less than conventional instruction per unit of effectiveness.[17]

These results do not necessarily apply to elementary and secondary institutions, but they do demonstrate the value of explicitly accounting for the costs of various modes of instruction.

Other researchers have made notable efforts to experiment with cost data and with models of cost-effectiveness in the world of elementary and secondary education. For example, a study of mathematics achievement, mathematics attitude, and computer literacy at the Westberry Elementary School in Saskatchewan, Canada, found that:

- students who were exposed to computer-assisted mathematics instruction improved significantly more in mathematics than did students who were exposed to traditional mathematics instruction;
- students who were exposed to computer-assisted mathematics instruction improved significantly more in computer literacy than did students **who** were exposed to traditional mathematics instruction;
- students' attitudes toward mathematics were not significantly affected by computer-assisted instruction; and
- computer-assisted mathematics instruction was more cost-effective than traditional mathematics instruction for producing gains in mathematics achievement.[18]

As the authors emphasize in their conclusions: "This study is not intended to be the final word on the costs, effects, and utility of microcomputer-assisted instruction."[19] It is an example of the usefulness of the methodological approach and contributes constructively to the policy debate over efficient ways to improve mathematics achievement.

State governments, which now pay the largest share of public school costs, have to balance claims for education against claims for highways, public welfare, health and hospitals, and natural resources. It is essential that they raise the question of costs when deliberating over continued funding for computers and other resources. The exemplary efforts of one State are described in box 4-A.

Cost-Effectiveness Analysis in Practice[20]

Westberry Elementary School, in Saskatchewan, Canada, serves 422 students (K-7) with a professional faculty of 20. About 73 percent of the students live in the town of Kindersley, with a population of just over 5,000. The remaining 27 percent live on farms in the rural area surrounding Kindersley. The school is ideally suited for comparing the effect of two treatments on a group of students, because there are at least two classrooms of students at each grade level. Prior to the 1984-1985 academic year, Kindersley schools had implemented computer literacy programs for junior high school students and computer science programs for high school students. However, no computers were being used in elementary school.

[16]Dexter Fletcher, Institute for Defense Analyses, personal correspondence, Oct. 4, 1986.

[17]See Dexter Fletcher and Jesse Orlansky, "Cost Effectiveness of CBI in Defense Training, " paper presented at the American Educational Research Association, 1986; and Jesse Orlansky, "The Cost-Effectiveness of Military Training," paper prepared for the *Proceedings of the Symposium on the Military Value of* Cost *Effectiveness of Training,* DS/A/DR (85), 167 (Brussels: NATO Headquarters, Defense Research Group on the Defense Applications of Operational Research, January 1985).

[18]D Hawley et al., University of Oregon, Center for Advanced Technology in Education, "Costs, Effects and Utility of Microcomputer-Assisted Instruction," Technical Report, 1986. See the section in this chapter on "Cost-Effectiveness Analysis in Practice" for a discussion of how this study was designed and carried out.

"Ibid., p. 33.

[20]This section summarizes Hawley et al., op. cit., footnote 18.

Box 4-A.—Arkansas Project IMPAC

In Arkansas, policymakers are concerned about improving instruction and encouraging educational accountability. To this end, Arkansas established basic skills requirements and implemented a statewide testing program to measure student achievement. Recognizing the potential of educational technology, but faced with limited resources, the Arkansas legislature established the Commission on Microcomputer Instruction in 1983, to determine cost-effective ways of using new technologies to improve the teaching of basic skills in the State's elementary schools. The Commission included educators, State legislators, and members of the business community. It established the Instructional Microcomputer Project for Arkansas Classrooms (IMPAC) and IMPAC Learning Systems Inc., a nonprofit company that uses State and private resources to purchase computers, develop software, and provide maintenance and support to project schools. First implemented in 22 schools, IMPAC has expanded to 136 schools, 1,000 teachers, and 30,000 students. The budget for IMPAC increased from $2.5 million for the first 2 years to $4.1 million for 1987-88.

Since 1983, IMPAC has tested and refined approaches that combine regular classroom instruction with computer-managed and computer-assisted instruction (CMI and CAI) to teach basic skills. Four different kinds of programs have been developed, implemented, and evaluated: CMI/CAI networked to the classroom; CAI; CMI/CAI computer laboratories; and computer-assisted instructional management (C-AIM), a testing and CAI program for improving the management of mathematics instruction. In all IMPAC classrooms, software is closely linked to the Arkansas Basic Educational Skills List, and student learning outcomes are measured by scores on the State's basic skills tests.

In IMPAC classrooms, the teacher employs traditional methods of instruction 80 percent of the time and computer-based instruction 20 percent of the time. Students use the computers for 15 to 20 minutes a day in either networked classrooms or computer laboratories to work on mathematics, reading, or language arts skills. Teachers determine which basic skill objectives will be taught with CAI and how the software will supplement and enrich the regular instructional program. Students in IMPAC classrooms show a higher average achievement gain on the State basic skills tests than do students in regular classrooms. IMPAC CAI and C-AIM mathematics programs have been the most successful. According to IMPAC administrators:

> When CAI or CMI/CAI is implemented in this methodical and skill-oriented manner, significant improvement in learning can be effected. Students can be motivated to achieve, and teachers can learn to be more efficient and effective in the management of instruction.[1]

IMPAC staff monitor costs to determine the most efficient and cost-effective ways to use computers in Arkansas schools. To reduce program costs, IMPAC supervises the purchase, installation, and repair of all hardware, the selection and purchase of all software, inservice training, demonstrations, and evaluation of projects in participating schools. Says Cecil McDermott, Director of IMPAC:

> We have found, for example, that by monitoring costs we can effect changes that result in a businesslike approach to improving programs. We have been able to cast out certain microcomputer systems and cast out certain software as a result of this process, and we've been able to manage growth.[2]

With volume discounts for hardware, a statewide license agreement for software, responsibility for hardware installation and repair, IMPAC reduced program maintenance costs by 40 percent: in 1986-87, the project maintained 2,600 computer systems in IMPAC schools at a savings of $80,000 to the State.

The typical IMPAC project costs 45 percent of what other States are paying for similar programs. "An IMPAC lab can be designed, work stations built, rooms wired under strict electrical specification, hardware ordered and drop-shipped, hardware installed, and in-service training completed for teachers and aides within three months."[3] IMPAC has figured program costs to be $104 per student per year over a 5-year period, a cost that is lower than comparable packages available from commercial vendors. According to IMPAC analyses, the program is more cost-effective than reducing class size or increasing regular instructional time, but less cost-effective than tutoring provided by paid adults, especially those used in Chapter 1 programs.

[1] Cecil McDermott and Betty Deaton, "Model for Supplementary Computer-Based Basic Skills Instruction," *Thrust* (Association of California School Administrators), vol. 16, No. 5, February/March 1987, p. 15.

[2] Cecil McDermott, Project Director, Arkansas Commission on Microcomputer Instruction, Arkansas Department of Education, personal communication, 1988.

[3] Arkansas Commission on Microcomputer Instruction, *Legislative Update on Basic Skills Project Under Act 528 (1983)* (Little Rock, AR: Arkansas Department of Education, July 1987).

Beginning in October 1984, one computer was placed at the disposal of the elementary school staff.

The study involved students in grades 3 and 5, and used a pretest-posttest control group design. **All students were given a pretest to measure mathematics achievement, attitude toward mathematics (interest in the subject and how much they like doing mathematics), and computer literacy. Then students in each of the two grade levels were randomly assigned to two groups: the control group at each grade level received traditional mathematics instruction, while the experimental group at each grade level received computer-assisted mathematics instruction. Following these treatments each group was given a posttest to measure achievement, attitude, and computer literacy.**

The control group followed a standard schedule of traditional instruction, averaging 55 minutes per day. The third grade class used the *Series M Mathematics SI Edition* textbook, along with other materials such as flash cards, clocks, and oral mathematics drill games. The experimental group was taught by the same teacher, who had received 2 hours of prior training on the computers. These students used the *Milliken Math Sequences* software, a program which has been widely used in schools throughout Canada and the United States. The fifth grade control group had 45 minutes per day of instruction, using the Holt *Mathematics System*. **The same teacher taught the computer-using group, in which each student received 10 minutes of mathematics drill on 3 out of every 4 days and 15 minutes on the fourth day, using the Milliken** *Math Sequences* software.

Costs.–An accounting of the costs of adjunct computer-assisted mathematics instruction as compared to traditional mathematics instruction included the following elements:

- Personnel
  - —teacher salary and benefits
  - —program management
  - —supervision costs
- Facilities and renovation
  - —classroom
  - –furniture
- Equipment and materials
  - —textbooks
  - —computer hardware
  - —computer software
- Other costs
  - —training
  - —energy

The method for annualizing costs of ingredients, by incorporating depreciation and interest,[21] led to the development of cost data shown in table 4-5.

Effects Measurement.—The effects of computer-assisted instruction compared with traditional mathematics instruction were assessed through six measures: the Canadian Test of Basic Skills (CTBS) Mathematics Computation Subscale, the CTBS Math Concepts Subscale, the CTBS Math Problem Solving Subscale, the CTBS Total Mathematics, the Survey of School Attitudes Mathematics Subscale, and the Computer Literacy Test. The CTBS Total Mathematics results, which were used in the cost-effectiveness analysis, are shown in table 4-6.

Results of Cost-Effectiveness Analysis.–The purpose of this study was to determine the cost per unit of achievement gain under each treatment. As mentioned earlier, this study found that students who were exposed to computer-assisted mathematics instruction improved significantly more than other students in several areas, and that this method of instruction was more cost-effective than traditional instruction. For example, as shown in table 4-7, both third and fifth graders who used CAI experienced almost twice the gain of their peers who had traditional instruction; and while the cost per student was higher for CAI than for the traditional method, the *cost per unit of effectiveness* was significantly lower.

[21]Levin, op. cit., footnote 4.

Table 4-5.—Total Annual Costs Projected for Grades 3 and 5 Mathematics Instruction in Westberry Elementary School[a]

	Grade 3		Grade 5	
Measure	Traditional	CAI	Traditional	CAI
Annual cost	$31,379	$34,389	$48,094	$52,406
Additional cost of CAI[b]	$3,010		$4,312	
Percent difference	9.59		8.97	

[a]Projections assume four 55-minute periods of mathematics instruction provided to 20 students in each period for 197 school days.
[b]Increased annual costs projected for adjunct computer-assisted mathematics instruction.
Abbreviation: CAI = computer-assisted instruction
NOTE: All costs are in 1985 Canadian dollars.

SOURCE: D. Hawley et al., University of Oregon, Center for Advanced Technology in Education, "Costs, Effects and Utility of Microcomputer-Assisted Instruction," Technical Report, 1986, p. 21.

Table 4-6.—Total Mathematics Mean Scores for Grades 3 and 5: CAI and Traditional Instruction in Westberry Elementary School

	Grade 3		Grade 5	
	Traditional (n=21)	CAI (n=20)	Traditional (n=19)	CAI (n=19)
Pretest				
Mean raw scores	46.38	42,55	62.05	59.26
Mean grade placements	3.42	3.29	5.53	5.32
Posttest				
Mean raw scores	52.90	56,40	71.68	76.11
Mean grade placements	3,71	3.86	6.03	6.20
Significance	p< .05		p< .05	

Abbreviation: CAI = computer-assisted instruction

SOURCE: D Hawley et al., University of Oregon, Center for Advanced Technology in Education, "Costs, Effects and Utility of Microcomputer-Assisted Instruction, " Technical Report, 1988, p. 18.

Table 4.7.—Total Mathematics Grade Placement Gains, Costs Per Student, and Costs Per Month of Gain: Grades 3 and 5, Westberry Elementary School

	Grade 3		Grade 5	
Measure	Traditional (n=21)	CAI (n=20)	Traditional (n=19)	CAI (n=19)
Mean grade placement gain in months . . . . .,	2.86	5.70	4.94	8.89
Cost per student	$129.06	152.81	179,15	200.28
Cost per month of grade placement gain per student	$45.13	26,81	36.27	22.53

NOTE: Costs are in 1985 Canadian dollars.

Abbreviation: CAI = computer-assisted instruction

SOURCE: D. Hawley et al., University of Oregon, Center for Advanced Technology in Education, "Costs, Effects and Utility of Microcomputer-Assisted Instruction, " Technical Report, 1988, p. 22.

CONCLUSIONS AND POLICY DIRECTIONS

One of the risks associated with fervent application of cost-effectiveness models is that progress toward realizing new purposes of education will be delayed. As one education researcher points out:

> Comparing programs using technolog to traditional curricula rarely yields useful information since new programs have goals attuned to technological change, efficiencies attributable to technology, revised roles for students, and new responsibilities for teachers. . . . In general there are so many differences between the two approaches that comparison is silly. Often, material taught in technologically-based programs simply can't be taught in another way, and therefore is cost effective by any criteria. For example, flight simulators teach skills in dealing with emergencies that cannot be created in another way. In another example, the music micro world developed by Balzano's FIPSE project teaches music composition skills that could only be practiced if students had full orchestras available to try out their fledgling ideas. . . . Comparing costs of traditional and technologically-based programs usually fails because the goals and objectives of the programs differ substantially .22

At the same time, it would be unwise to ignore the value of CAI for doing what we currently want schools to do: help students master written and oral communication and mathematics, acquaint them with important areas of human knowledge, and enhance their ability and motivation to solve problems. The exciting future potential of computer-based technology in education does not diminish the concern for careful use of resources to achieve current purposes. Cost-effectiveness comparisons of computer-based programs in education *versus* "traditional practice," *versus* "innovations" not based on technology (for example, students tutoring other students, or some form of "cooperative learning") are still appropriate.

There is also the possibility that computers will not fulfill their potential in education because they do not prove cost-effective for achieving traditional purposes.[23] Most schools now have a computer for every one or two teachers—just as they have had movie projectors, radios, and televisions or videotape players in small numbers. But whether schools will ever acquire enough hardware and software to make computers a principal vehicle of instruction will depend in part on judgments of cost-effectiveness along the way.

OTA recognizes the many barriers to conducting credible cost-effectiveness studies. The Federal

[22] Marcia Linn, University of California at Berkeley, Graduate School of Education, "Evaluating Technological Applications m Higher Education: Seeking Promising Paths, " monograph, July 1986.

[23] Henry Levin and Gail Meister, Stanford University, Center for Educational Research at Stanford, "Educational Technology and Computers: Promises, Promises, Always Promises, " project report No. 85-A13, November 1985.

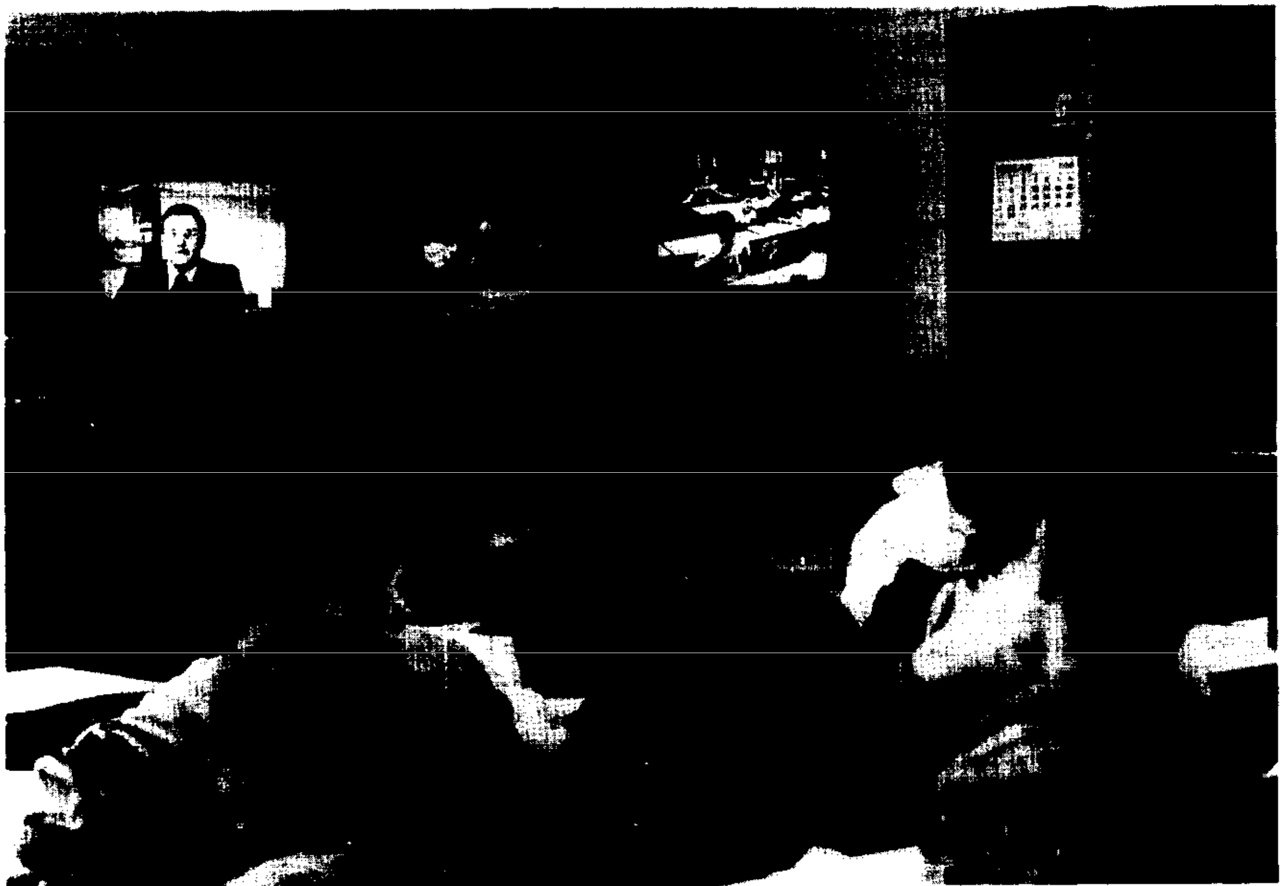


Photo credit: Bill Davie, Trinity Productions

Cost-effectiveness analyses must also evaluate alternative methods of providing courses, as in this distance learning course offered through the Northern Michigan PACE Project.

Government can encourage the use of this decision-making tool in the following ways:

- Provide technical assistance to the States and to local school districts who wish to evaluate cost-effectiveness of extant or proposed technologies. Preparing guidelines for data collection and analysis would be a good first step. In addition, the Federal Government could help establish standards for measurement of costs and effects, so that studies conducted in different school systems could be more readily compared.
- Provide access to computer programs for cost-effectiveness analysis. In addition to helping States and districts conduct studies, this would have the benefit of creating a database of findings to be shared by interested parties.
- Conduct a demonstration cost-effectiveness study. By evaluating current programs, such as the use of computers in Chapter 1 schools, the Federal Government could provide a role model for States and districts.
- Fund research on cost-effectiveness methodologies. This would enhance the apparatus of cost-effectiveness analysis to allow for multiple educational outcomes, time constraints, and dynamic aspects of costs and benefits.[24] In addition, attention could be devoted to techniques

[24]See, for example, A. Charnes et al., "Measuring the Efficiency of Decisionmaking Units," *European Journal of Operational Research, vol. 2, No. 6,* November 1978. Extensions to the basic technique allow for multiple outcome measures: see Anand Desai, University of Pennsylvania, "Extensions to Measures of Relative Efficiency With an Application to Educational Productivity," doctoral dissertation, 1986; and Anand Desai and A.P. Schinnar, Ohio State University, College of Business, "Methodological Issues in Measuring Scholastic Improvement Due to Compensatory Education Programs, " Working Paper No. WPS-1987-19, 1987.

that incorporate the future probability of increased effects and / or decreased costs, which would add an important dimension to the static measure of known costs and effects. This line of analysis, which would introduce future innovations in technology as an *output* of current uses of available technology, as well as an *input* to future learning processes, could provide insight to the cost-effectiveness of new technologies (such as interactive video and distance learning), for which there is as yet very limited experience.

Chapter 5
The Teacher's Role

Photo credit: Blue Earth Elementary School, Blue Earth, Minnesota

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Chapter 5

The Teacher's Role

"While our system of schools contains many consequential characteristics . . . none is more important than who the teachers are and how they work. Without good teachers, sensibly deployed, schooling is barely worth the effort. "

Theodore Sizer[1]

INTRODUCTION

Educators and educational researchers consistently cite one factor as central to the full development of technology's use in the schools—the classroom teacher. Computers, though powerful, are not self-implementing. But in the hands of a creative and technically competent teacher armed with appropriate software, the computers and allied technologies can provide a new world of teaching opportunities. They are the newest, most versatile tools of the teaching trade.

This chapter, while dealing with the teacher's role in the effective use of technology in schools, focuses on the use of computers for several reasons. As stated elsewhere in this report, many of the emerging interactive technologies are computer based. And, although technologies such as distance learning and interactive videodisc are becoming increasingly important in K-12 schools, they are currently used less than the computer. While instructional television through the videocassette recorder (VCR) is experiencing a renaissance in the schools, it also often serves as the ". . . spark plug for educational chain reactions incorporating computer applications such as word processing or computer simulations."[2] Finally, all interactive technologies raise similar issues: how do teachers use them and why, how does their use affect the teacher's role, what training do teachers need to take advantage of them, and what barriers stand in the way of fuller utilization?

[1] Theodore Sizer, *Horace's Compromise: The Dilemma of the American High School* (Boston, MA: Houghton Mifflin Co., 1984).

[2] See Milton Chen et al., *Case Studies of Exemplary Instructional Television Use* (San Francisco, CA: KQED Instructional Television, January 1988).

FINDINGS

- **Despite the presence of computers in almost all K-12 schools nationwide, only half of the Nation's teachers report that they have used computers in instruction. Barriers to use are both practical (inadequate access to the technology) and intellectual (initial fears of using the technology and a lack of understanding of the computer's value in serving** the curriculum).
- **Few teachers have found ways to exploit the enormous potential which interactive technologies offer. Use in most cases is adapted to the curriculum at hand and the teacher's existing teaching methods. Teachers are just beginning to understand the computer's potential for helping** students solve problems, think for themselves, and collaborate with other students. The computer can help shift the teacher's role from education dispenser to coach, guiding and encouraging each student to become an active participant in his or her own learning.
- Most teachers want to use technology. Some of their reasons are personal: the desire to develop professionally, to learn the newest tool of the trade, and to do their jobs better. Some are centered on benefits they see for their students: preparation for the world of technology outside school and a vehicle to channel the students' enthusiasm for technology into creative learning. Other rea-

sons include fear of being left behind or being replaced by the technology, and pressure from parents, school boards, and administrators.

- The process by which teachers appropriate technology is more complex than that by which teachers adopt other changes. Initial fears regarding technology may need to be overcome before teachers feel in control. Training with computers is an ongoing process that takes place at varying levels, depending upon the teacher's responsibilities and the way the technology is to be used. Teachers need opportunities for practice with the computer, with continuing support from trainers or computer-using peers. Once teachers feel comfortable with the computer as a tool to help them do their job, they look for ways to integrate it into their existing curriculum and seek opportunities to do things previously impossible in the classroom. Few then wish to go back to teaching without computers.
- Teachers use computers in ways that work best with their own teaching styles and methods, but these styles evolve as teachers gain more computer experience. Some teachers individualize instruction, encourage individual and group problem solving, and enhance peer learning when they have computers in the classroom. Activities facilitated by computer use include teaching writing, doing laboratory experiments in science, solving sophisticated problems in mathematics, or using simulations in social studies classes.
- The very opportunities opened by the computer can create more work for the teacher, making the job harder initially. Although the computer can minimize some administrative chores and ease classroom discipline, other tasks which accompany computer use (individualizing lessons, matching software to the curriculum, scheduling student computer time, monitoring use, providing assistance, and troubleshooting) add a net burden to the teacher's time in the short term.
- The teacher reform movement has created special challenges and opportunities for the application of technology to education. As more teacher education programs become 5-year programs, with students earning undergraduate degrees outside of education, computer training will need to be sandwiched into a tighter teacher preparation curriculum. Integrating the use of technology in subject matter courses can be an effective way of making computer skills part of preparation of new teachers. Having student teachers intern with computer-using classroom teachers can also provide role models for technology use.
- Preservice technology training, while important in giving prospective teachers facility with the computer, only serves as an introduction. Teachers need continuing training as the technology changes, as new and more effective applications are developed, and as more is learned about learning with technology.
- The Federal Government's role in training teachers to use technology has been a limited one, although Federal support was important in creating a "first wave" of computer-using educaters. The major players in supporting teacher training have been the States and local districts. They have made substantial financial commitments to preparing teachers to use computers, but this support has been highly variable across States and districts.
- Any further investment in technology for education must factor in teacher training and support, whether that effort is focused on a few specialized teachers or on all teachers. Although most of the responsibility for training will fall on local school districts, there are important ways to use the resources of intermediate education agencies, States, the Federal Government, and the private sector.
- School administrators must support and encourage teachers to use technology throughout the curriculum. For this to occur, they too will need training that provides them with an understanding of instructional applications of computers and a vision of the potential for change they offer.
- **Efforts to support teachers require attention to more than immediate needs and current practice. The technology offers new possibilities for enhancing the teaching environment and teachers' personal and intellectual growth. Teachers need an environment in which they can feel free to experiment if they are to discover the opportunities that the technology can provide.**

HOW TEACHERS USE TECHNOLOGY

Background: Teacher Attitudes

Almost all teachers want to use technology.[4] Some of the reasons cited are related to personal growth, some to concern for students, and some are reflective of external pressures. Being professionals, most teachers want to stay abreast of the latest developments in their field. As one teacher stated: "I always made the commitment that when I became a teacher who didn't want to do the new things or at least investigate them and give it a good shot, then I didn't want to teach anymore.'" Some see the use of computers in all aspects of society as inevitable. They want to be able to prepare their students for the outside world. Many have used computers at home and are intrigued by the possibilities they offer, or they have observed their students' enthusiasm for computers and want to channel that enthusiasm to the classroom.

Some have seen the computer's potential as a tool to do things in the classroom they had been unable to do before. "In some ways I'm rewriting the curriculum. I can't show on a blackboard a thousand balls dropping through a triangular grid. And to get a distribution, I want a graph to talk about theoretical and experimental probability. So I use computers a lot for simulations. " They understand from experience that students learn in different ways. "Having computers in the classroom can help provide different kinds of learning experiences for students; for example, the visual learner, or those overwhelmed by the large classroom and all its distractions, who really pay attention to the focus of the computer screen. "

For many teachers, the computer lights a fire under their teaching spirit, rekindling waning enthusiasm for teaching. As one teacher said, describing her colleague, "The use of computers in teaching gave him a new lease on life. This is all he talks about—what his students did in class. He's really excited about it!"

Finally, some teachers admit that they are responding to outside pressures. Administrators and parents want teachers to use the machines that have been placed in their classrooms. Having computer skills can also open doors to new jobs in the schools, as in cases where teachers avoid staff cutbacks by switching to positions that involve computers. Pressure from teacher peers can also be a strong motivator. When asked to describe the relationship between teachers who use computers in their classes and those who do not, one teacher stated, "It's the advocates versus the guilty!"

Yet, not all teachers embrace computers with open arms. As one teacher said: "They rolled this thing (the computer) into my class and said, 'Here, it's yours for the month. ' What did I want with it? It was a distraction. I let each kid have a half hour on it and the other 23 would be looking at the clock the whole time, saying 'Is it my turn yet?' By the end of the first week I just used it as a place to throw the kids' coats on. " Others express their concern in more positive terms: "I don't plan to use it and don't feel the need to apologize. I teach the way I teach because it works for me and my students. I'd rather take a course in the summer on Greek tragedy so I can add that to my literature course, than a course in how computers work. It's a question of allocating a valuable resource, my time, where, in my professional judgment, I can best nourish my own growth and that of my students. "

Finally some teachers fear that their students may lose important underlying skills, such as penmanship or computation, when adopting new technologies that replace these skills. Fearing the loss of the old in adopting the new is not a novel concern. In the words of an early critic of technology: "Those who acquire it will cease to exercise their memory and become forgetful; they will rely on (it) to bring things to their remembrance by external signs instead of on their own internal resources. " He went on to criticize this new technology for replacing a human response with a manufactured artifact and

[3] This section draws heavily on Martha Stone Wiske, Harvard University, Educational Technology Center, and Phillip Zodhiates, Education Development Center, Inc., "How Technology Affects Teaching," OTA contractor report, October 1987.

[4] As early as 1982, a National Education Association random sample of approximately 1,200 teachers revealed that 83 percent of the teachers surveyed wanted to take a course to learn how to use a computer for Instructional purposes. Seventy percent or more believed that computer use in schools has a positive effect on student motivation, subject Interest, attention span, self confidence, and cognitive learning. National Education Association, *Teacher Survey NEA Report: Computers in the Classroom* (Washington, DC: 1983).

[5] The comments in quotes are derived from teacher interviews conducted for OTA by Wiske and Zodhiates, op. cit., footnote 3.

for cheapening learning by democratizing access to knowledge. The critic was Plato, in *Phaedrus*, arguing against the introduction of writing in ancient Greece.[6]

Some of the objections voiced by teachers are based on prior skepticism, partial information, bad training, and lack of exposure to uses of computers. Teachers (and others) also tend to blame computers for problems caused by the people who use them poorly. Without contact with effective computer-using teachers they have no positive models. (See box 5-A.[7])

[6]As cited in James Cummins and Dennis Sayers, *MicroTrends: Computer Writing Networks and Empowerment* (Reading, MA: Addison-Wesley, in press).

[7]The portrait in this box and in boxes 5-B and 5-C are composite profiles of fictionalized teachers who illustrate common themes of teachers' varying approaches to technology use in the classroom. The

(continued on next page)

Box 5-A.—Deciding Not To Use Computers[1]

"Charles Perry" is the chairperson of the English Department at an affluent suburban high school of 1,100 students. A teacher for 21 years, Charles has an M.A. in English. By all accounts, Charles is a masterful teacher who knows exactly what he wants to accomplish in the classroom.

Charles took a 1-day inservice computer course 10 years ago: "[I] got nothing out of it. They went so fast; I was lost. The manual was unreadable," he recalls. Since then he has observed colleagues going through similar training experiences, which he blames on computer enthusiasts who ". . . go flying off without you and make you feel stupid."

Charles offers no apologies for his decision not to use computers in his teaching even though computers are available in his school. "Sure, with time and better instruction I could learn how to use them, but the computer just isn't important to me," he says. "I'd rather spend my summers writing than taking computer classes." Describing himself as a ". . . 19th century person kicking and screaming my way into the 20th century," he is profoundly skeptical of the usefulness of computers. "What's it for?" he asks in an exasperated tone. "I don't see that thinking—the kind of thinking you'd want for citizenship—is enhanced by these machines." Unlike many teachers of writing, Charles finds that the word processors discourage rather than facilitate revising and editing. "My kids do all their papers on word processors at home and they don't seem to be as long or rich as they were when done in longhand and then typed." He thinks the problem is that many students are satisfied with turning in their first drafts: "They think that because it looks neat, it's done." Charles believes that until teachers as a group demand more rewriting they are not going to see much improvement. And he worries that many teachers are also seduced by the neatness of computer-produced papers.

Like many good teachers, Charles cherishes the "on-stage" performing aspect of his job. He sees computers as a source of competition for the students' attention and suggests that technology may have the greatest appeal for teachers who are less successful at holding the attention of their students and therefore want to try a different pedagogical approach.

In addition, Charles associates computer use with a style of teaching he mistrusts. He points to a coworker, "a very casual kind of person," who now spends less time on traditional instruction while students play around on the computer. He is also dismayed by his impression of the computer laboratory next to his classroom, describing it as a chaotic place where children receive little supervision. He fears that technology is tempting teachers to relinquish their instructional role and become ". . . just facilitators of student computer use."

Finally, Charles fears that computers will disrupt the traditional student-teacher relationship. He has heard horror stories of colleagues using drill and practice software in which ". . . a kid can just push a button and the teacher has no way of knowing whether he has the wrong answer or not, unless he happens to be standing right behind him. There is nothing that feeds back to the teacher how each kid is doing." Having had no contact with teachers who find that the computer provides them with a valuable window on their student's thinking and learning, Charles is convinced that technology comes between teachers and students.

[1]Composite portrait prepared by Martha Stone Wiske, Harvard University, Education Technology Center, and Phillip Zodhiates, Education Development Center, Inc., "How Technology Affects Teaching," OTA contractor report, October 1987.

Uses in the Classroom

There is not "one computer in education"; there are many possible educational computer cultures.[5]
Sherry Turkle

There are as many ways teachers can use computers in the classroom as there are varying teaching styles. Teachers use groups of computers in laboratories very differently than one or two in the classroom. A single computer in a classroom can be used by the teacher in various ways at various times—sometimes as a provocative learning station for individual students, sometimes for interactive demonstrations led by the teacher for the whole class, and in other instances for collaborative problem solving by a small group of students. Use in social studies is different from that for science laboratory work; drill and practice for review of basic skills is very different from students programming a computer to make machines move. Indeed, asking, "In what ways do teachers use computers, and how does the computer affect the teacher and his or her teaching?" seems as broad a question as, "How do teachers teach with books and what effects do books have on teachers?" (See box 5-B.)

One of the most frequently cited areas where computers make possible things that could not be done before is in special education. The computer has been described by some as "the freedom machine, " opening the door to educational pathways previously inaccessible to handicapped or learning disabled students. For the physically handicapped, adaptive devices can make communication itself possible. For trained teachers with access to appropriate information, computers can be powerful teaching tools for special education students. (See box 5-C.) However, many special education teachers (and classroom teachers who have disabled students mainstreamed in the regular classroom) are not aware of what is available and what is possible, In addition, the educational system provides few if any incentives or rewards to teachers who go out of their way to see that their special education students have equal access to computers. As a result, the special education student, especially if mainstreamed into a regular classroom, often is placed, like the non-English speaking student," at the end of a long line when it comes to classroom computer use.

How the Use of Computers Can Change Teaching Style

One of the most significant impacts of the use of computers in the classroom is change in teaching style. Teachers can go beyond the traditional information delivery mode where they are presenters of ready-made knowledge and become facilitators of students' learning. With computers, students can work on problems individually or in small groups while the teacher acts more like a coach circulating among them and giving assistance. (See box 5-D.) Some teachers find that they are able to observe more of the learning process when watching students interact with computer-based materials. Some teachers welcome the opportunity to learn alongside their students: "I've become more of an involved participant than an authority figure . . . a learner with students rather than a presenter of facts. " For many, this is a significant change from how they were taught to teach. It can be both exhilarating and intimidating.

Teachers who use the computer as a medium that students can manipulate individually or in small groups find their students become more actively en-gaged in learning and thinking than during traditional lecture-oriented lessons. Such teachers use the computers to give students more responsibility for their own learning.[10] Students can work at their

(continued from previous page)

composites are drawn from Wiske and Zodhiates, op. cit., footnote 3. In this report a sample of 76 teachers, from 10 regionally diverse school districts, including urban, suburban, and rural sites, were surveyed in extensive telephone interviews. Twenty classroom teachers from various school systems in the Boston area were also interviewed. In the interviews, which lasted on average 1 hour, open-ended questions were asked concerning their personal classroom computer use, the computer training and support they had received, and their assessment of the impacts of the computer on their teaching style and on their students. In selecting the sample, the researchers attempted to balance for teacher position, gender, and extent and type of computer use. The composites are intended to draw a picture of, if not real people, real types of teachers, to give a feel for common categories and concerns. The device results in a cross between straight statistical survey research and hypothesis. See the Wiske and Zodhiates report for additional composite profiles.

[5] Sherry Turkle, personal communication, November 1987.

[9] See U.S. Congress, Office of Technology Assessment, "Trends and Status of Computers in Schools: Use in Chapter 1 Programs and Use With Limited English Proficient Students," staff paper, March 1987.

[10] See Sizer, op. cit., footnote 1, for a fuller discussion of the traditional American high school and the docility it engenders in students. In his report he states, "No more important finding has emerged from the inquiries of our study than that the American high school student, as student, is all too often docile, compliant, and without initiative." Sizer contrasts this to what he calls ". . the hungry student . active, engaged in his or her own learning. The student takes the initiative and works at teaching himself' (p. 54).

Box 5-B.—Using Computers in an Elementary Classroom[1]

"Laurie Adler" teaches first grade in a typical elementary school where she is responsible for teaching 26 students everything except art, music, and gym. She has taught for 14 years and has a bachelor's degree in elementary education. Four years ago she was unexpectedly given a computer to use in her classroom. Although computer use was not a required part of the first-grade curriculum, she believed she was expected to use the one she was given. "It was just dive in and get wet." She took one course offered by her district, but has basically taught herself by experimenting with games, educational software packages, and word processing. She continually reassured herself: "Not to worry, there's plenty of time to learn how to do this. These are little kids, I just have to keep a day ahead of them." Over the past few years, she has gradually felt more at ease using computers, discovering that "you can tell the computer what to do, that's basically what all the software is about. What a wonderful revelation—that it's not some magical machine!"

Laurie has had one computer in her classroom at all times and also has had access to several "floating" computers on carts. Her instructional approach with computers is flexible. The computer serves as a "learning station" in her classroom. "I've found that it just fits in with the way I like to do things during school. . . . Having a computer in the classroom helps me to keep more of an individualized approach to teaching." Laurie also uses the computer for whole class lessons and small group work. Her students use some mathematics and reading software, but they use the computer mostly for writing. The children have written short stories and poems far superior, she believes, to what they would have produced with paper and pencil. Because her students are always enthusiastic about using the computer and find that writing can be fun, she believes that the computer has had a positive impact. She observes longer attention spans and more patient behavior in her students. Moreover, by working together on the computer, her students are beginning to appreciate each other's strengths.

Initially, Laurie found that having a computer in the classroom presented logistical problems. "There were a lot of interruptions in the rest of the class when these kids were working on the computer. Then I found it works to have a master computer pal on a rotating basis, a child who really knows a piece of software, to whom those using the computer can go for questions rather than coming to me." She believes that computers encourage a sense of community in her class. Students often choose to work together on the computer; sometimes two children even share a chair.

Laurie thinks teaching with a computer is a little more difficult—the computer makes her work harder. "I have to keep things very focused in terms of the kinds of projects we're working on to be sure that all kids have an opportunity to use the computer." Each week, she makes up a schedule to ensure that everyone will have a chance to work on the computer once or twice a week for about 30 minutes. Laurie would use computers even more extensively if only she had more—more computers, more time, and more training. For now, she arrives at school early to prepare materials, and sometimes works late into the afternoon as well. Although no monetary rewards or special status are associated with knowing about or using computers in her school, Laurie says: "You know where the reward comes: it comes when children choose to stay after school, to come in at 8:00 o'clock in the morning to work on the computer, and when parents says that they appreciate the extra effort that you've made. I really appreciate that."

[1]Composite portrait prepared by Martha Stone Wiske, Harvard University, Education Technology Center, and Phillip Zodhiates, Education Development Center, Inc., "How Technology Affects Teaching," OTA contractor report, October 1987.

own speed and can figure out more for themselves. Some students who do not respond well to lessons based around a lecture format deal more positively with the interactive, visual medium of the computer.

The typical school today has a specialized computer laboratory and/or a few classrooms with one or two computers each.[11] As demands for separate computer literacy and programming courses diminish, some schools are moving their stand-alone com-

[11]See ch 8, Box 8. A_ Apple Classroom of Tomorrow, for a description of the exceptional case of classrooms where every student has a computer on his or her desk.

Box 5-C.--Using Computers With Special Education Students[1]

"Chris Johnson" teaches special education: learning disabled, *mentally retarded*, physically handicapped, and speech impaired students ranging in age from 12 to 18 years in a large urban high school. Several years ago Chris enrolled in a graduate level course on educational uses of the computer. He saw the possibilities of using computers for individualized instruction and enhanced social interaction with his students, but realized that available software would need to be adapted or new software "invented" to meet his students' special needs. It was embarrassing for his students to use elementary school software when they were in high school. He wrote a mini-grant proposal to a hardware manufacturer to adapt promising special educational materials, making them user-friendly and suitable to the structure and pacing of a special education classroom. As a result, he was awarded two computers for his class.

Chris explored various ways to apply the computer to his teaching. He has used the program Printshop as a business venture to help students develop vocational and social skills. Word processing skills have been particularly important for improving student self-esteem when, perhaps for the first time, a disabled student produces something legible that could be put in a book and shown to parents or friends with great personal pride.

Like many computer-using teachers, Chris views the computer as a tool that can do many things. Perhaps the most telling reason for Chris' enthusiasm is the computer's role as "equalizer" among his students and between them and other students in the school. He has instituted a peer buddy system to promote this process, pairing a special education student with a mainstreamed student to work together on computer activities. "My retarded kids could whup those regular kids with some of the memory games and some little spelling games and things like that. I think it was one of the first times that the regular kids perceived this normal competency level in handicapped kids." He has observed how the computer allows students with disabilities to find common ground with other students in the school. He also believes that many of his handicapped students will later in life need to interact with machines on the job or at home. School experiences with computer-based technology can present the handicapped learner with opportunities for future success.

Chris claims that the presence of computers in his classroom has made a substantial difference in the way he teaches. Some software has led him into content areas he would not otherwise have explored. The adaptation and invention of other software programs for special students has forced him to concentrate on students' control over their environment and over their own learning. He has observed his students using the computer to open new channels of communication with their peers, especially those students who have had difficulty with the social dynamics of the classroom, in making friends, or working with others. "I've had romances form around the computer;" for some of the students it was a deflection of having to work that difficult interaction of male/female roles. His enthusiasm is tinged with the understanding that computers are costly and require alot of his time to organize their use in the classroom, but he is undaunted. "The most compelling reason for using computers with special education students is that they work. They function as a multipurpose coping mechanism and as a catalyst to better social interactions, particularly important features of academic success in the special education classroom."

[1]Composite portrait prepared by Martha Stone Wiske, Harvard University, Education Technology Center, and Phillip Zodhiates, Education Development Center, Inc., "How Technology Affects Teaching," OTA contractor report, October 19S7.

puters into individual classrooms. Many teachers have found that having only **one or a few** computers in the classroom requires students to work together. This stimulates cooperative learning and peer teaching among students, and develops their communication and social skills. Even simple drill and practice programs may be used with-pairs or triads of students at one terminal taking turns and helping each other.

For example, OTA staff observed a junior high English for Speakers of Other Languages classroom, where three boys, one from Honduras, one from Laos, and another from Pakistan, worked together at the computer puzzling over a multiplication / division drill software program written in English. The boys' skills in spoken and written English were limited and varied, but together they encouraged each other to solve the mathematical problems so

Box 5-D.—The Teacher as a Coach: Teaching Science With a Microcomputer-Based Laboratory[1]

Douglas Kirkpatrick teaches an eighth grade physical science class in Walnut Creek, California. Working with a research team from the nearby Lawrence Hall of Science, he has been using the computer as a "silent laboratory partner," helping his students understand concepts in heat and light in a new way. His 32 students are teamed up in pairs using 16 microcomputers donated by Apple. The software is made up of microcomputer-based laboratory (MBL) materials, temperature probes, light probes, and heat pulsars for the collection of data, with accompanying curriculum materials, all developed by the Technical Education Research Centers in Boston.

Kirkpatrick found that his students had reasonable intuitions about the effect of insulation on the temperature of a liquid— gained from their prior experience with styrofoam cups—and the relationship between volume of a liquid and the amount of heat that needs to be added to make it boil—gained from heating large and small quantities of liquid in the kitchen. However, Kirkpatrick's students, like other science students, had persistent misconceptions about other scientific phenomena. As he noted, many students believed "you only have a temperature if you are sick," or "you have more hot chocolate, so yours is hotter than mine," or "temperature is all the degrees, but heat only refers to temperatures that are above warm." Merely telling students how heat differs from temperature or having them read about it in a textbook has traditionally had little or no effect on these entrenched misconceptions.

In the past, Kirkpatrick had clustered his students in small groups in a laboratory to study temperature. He had them observe water and moth flakes cooling, with some students calling out times and temperatures while others painstakingly recorded the data. Later, teams constructed graphs of their efforts and attempted to relate the curves on the graphs to key moments in the experiments. While students typically found these laboratory experiments more interesting and fun than a lecture or reading about temperature, the underlying cognitive concepts still did not seem to take hold.

Doing the experiment with the MBLs, Kirkpatrick's students were freed from the tedious mechanics of data collection, enabling them to focus on changes occurring before their eyes as recorded on the computer. Having the computer simplified experiments that would otherwise have been confusing. Real-time computer graphing was an antidote to their typically limited adolescent attention spans. His young experimenters, like "real" scientists, were able to use technological tools to collect, display, and analyze data, freeing them to concentrate on the effect of the experimental action, to observe, discuss, and analyze. Students were able to repeat their experiments easily when they had questions. They could also readily compare results with their fellow students, giving rise to lively class discussions about the meaning of the experiments.

If the computer was the silent laboratory partner, what was the teacher's role? Like any laboratory situation, where students have a hands-on engagement with learning, the teacher became a coach. In this instance, Kirkpatrick found that most students at first completely trusted the data from the computer. It was Kirkpatrick's job to direct their attention, to help them become aware of sources of invalid data, to teach them to diagnose the causes and help them evaluate data the computer collected. He taught them to detect poorly calibrated probes, discard data from such probes, and to recalibrate their scientific instruments. He guided their discussion to confirm their understandings.

Kirkpatrick has been delighted by the interactions he has observed among the students, and presides over countless fascinating classroom discussions of complex science concepts. He says, "I can't imagine a physical science laboratory without computers anymore."

[1]This is a nonfiction account of the activities carried out by a real classroom teacher. See also Marcia C. Linn, University of California at Berkeley, "Using the Computer as a Laboratory Partner: Cognitive Consequences," paper prepared for the symposium on "Computers in School: Cognitive and Social Processes" at the Second EARLI Conference, Tubingen, Germany, September 1987.

Photo credit: Computer Learning Month

"1 learn a lot more about my students because I can watch them learn. Before, I couldn't watch them learn, because I was busy delivering the curriculum. **My** role has changed with computers. "

—OTA teacher interview.

they could "win" the game. Three boys, three languages, one computer. Together they succeeded where one alone would have been lost. The teacher, busy elsewhere in the classroom, was available to them but was called upon for assistance only when all three were stuck on a point. Besides learning the mathematical facts at hand, the students were learning other social and communication skills equally important for school success.

Cooperative learning at the computer works particularly well in classroom activities using simulations and problem solving software. Students can be grouped with mixed abilities and work together on tasks that cannot be completed individually. Many software simulations are designed with the assumption that only one or a few computers are available for a whole class. Such simulations also provide opportunities for teachers to integrate various disciplines. For example, teachers using the popular simulation *The Oregon Trail*, which puts students into the role of early pioneers, have incorporated subject areas beyond social studies: language arts (having students keep journals); mathematics (in planning purchases for the trip); art (making maps and drawings for the walls illustrating the journey); science (learning about climate, wildlife, and nutrition during the trip), and music (singing songs of the pioneer days).[12]

Group learning with the computer engages students as actors and decisionmakers and channels their need to feel important as contributing members of a team. Too often this need is met only by after-school activities, such as band, play production, or putting together the school newspaper.[13]

This cooperative, group learning model has of course been used in other situations without computers as the focal point, but the interactivity of computer simulations and the machine's management of content frees the teacher to observe the groups in action, and to concentrate on the art of leading the students in their analysis and discussions.

Not all teachers welcome this change in the teacher's role. For some, it can be threatening. "If all the eyes in the classroom aren't on me, I'm not teaching. " Others wonder, "Are the teachers who are not successful with traditional teaching methods the ones who switch over to using the computer?"

Other computer-using teachers report that computers have exerted little or no influence on their personal classroom behavior. These reactions reflect

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[12] Holly Jobe, Montgomery County Intermediate Unit 23, Erdenhelm, PA, "A Look at Cooperative Learning in the Computer Classroom," *interface: Montgomery County Microcomputer News*, vol. 4, *No. 3*, November 1987, p. 2.

[13] 'Research has documented the powerful value of peer learning. Researchers studying the introduction of LOGO in classrooms have seen a "restructuring of expertise" which included peer expertise recognized by students. See Jan Hawkins and Karen Sheingold, "The Beginning of a Story: Computers and the Organization of Learning in Classrooms," *Microcomputers and Education: 85th Yearbook of the National Society for the Study of Education* (Chicago, IL: University of Chicago Press, 1986), pp. 40-58.

Photo credit: Center for Children and Technology, Bank Street College of Education

Peer learning and language development can take place as students work together at the computer.

different circumstances and styles of computer use. Since drill and practice or tutorial software is designed for use by individual students working independently from the teacher, it is understandable that teachers using such software find computers have little impact on their teaching style. They see the computer as a way of giving their students more "seatwork" or practice time, which they would otherwise provide with mimeograph practice sheets or other kinds of drillwork. Furthermore, presenting concepts to a whole class, then breaking the class into small groups to allow the children to become actively involved in solving problems, can be done with or without the computer. For teachers who have long used such methods, computers seem a natural extension of their arsenal of teaching tools. Finally, for many teachers, especially those in elementary schools who have classroom activity centers, the computer provides another engaging learning station.

Effects on Classroom Management

Almost all teachers who have taught with computers agree that, at least initially, most uses of computers make teaching more difficult. It takes planning to handle the basic logistics of scheduling[14] which students will use computers when and where, to make the necessary equipment and materials available, and to have a fall-back lesson in case the computer malfunctions. It also takes a great deal of planning to incorporate computers into a lesson. Much of today's computer software covers only one or a few instructional concepts. The teacher must

[14] In many schools, just getting access to the limited computers or laboratory time can be a major scheduling nightmare. This is another area where administrative support is important. Principals need to be aware of the scheduling issues (and equity implications) in determining who gets access to the equipment.

Photo credit Massachusetts Institute of Technology

"Computers give teachers a better opportunity to individualize, but that doesn't mean it's easy. Individualization is difficult to manage."

—OTA teacher interview.

find the best ways to incorporate sundry pieces into the overall curriculum. As one teacher said:

> It took me a while to get used to all this. It took me two months to understand what was going on . . . then a year to get good at it . , . to learn all the software programs and all the intimate details and intricacies of how the room worked. It took me a good year to be comfortable . . . but by the end of that time my room was pretty red-hot.

Although teaching with computers may require more preparation initially, teachers also report that technology eventually eases some aspects of classroom management. When students find their work on the computer engrossing, discipline problems decline. Absenteeism can be cut down, both by increased student enthusiasm for school, and through management systems such as automatic telephone calling systems that report to parents on unexcused absences in school.[15] Spreadsheets or special purpose grading programs, word processors, database managers, and desktop publishing can streamline many of the teachers' administrative burdens such as maintaining records and preparing materials.

Management tasks can be greatly simplified when teachers use networked systems. Some of today's integrated learning systems, which use large capacity storage systems on hard disc or compact disc-read only memory (CD-ROM), can hold thousands of individual lessons matched to the schools' curriculum, at levels ranging from primary through sixth grade skills, for the teaching of reading, language arts, and mathematics. Each student in the classroom can be working on a different lesson, with the management system automatically recording each student's progress, printing out for the teacher a detailed record of the student's work. The printout indicates which problems the student answered correctly, which were missed, and how long it took the student to complete the tasks. The teacher can then incorporate this information in planning which concepts must be reviewed when students return to the classroom, and cluster students by needs. By greatly easing recordkeeping and monitoring, these systems make it possible for the teacher to individualize teaching to a much larger degree.

Effects on Teacher Accountability: The Testing Question

One of the major issues in teaching is testing and teacher accountability, an issue that also has a di-

[15] "A recent study at the University of Tennessee examined alternatives for dealing with student absenteeism at nine comprehensive high schools, matched for their student body characteristics. Over a 60-day period, it was found that student absenteeism dropped 55 percent in schools where the parents of absent students were called by computer-based automatic calling systems in the evening, while student absenteeism dropped only 18 percent when parents of students missing school were called by school personnel during the school day. The computer-generated calling systems were found to be a much less expensive means of contacting parents. Maurice M. McDonald, University of Tennessee, "A Comparison of the Effect of Using Computer Calls and Personal Calls for Improving Pupil Attendance in Public High School s," doctoral dissertation, 1986.

rect bearing on use of computers and other technology in the classroom. Teachers' evaluations are often tied to students' scores on standardized tests that do not directly measure the progress of students who are tackling open-ended problems, collaborating with other students, and turning in assignments that require more than a right/wrong answer. [16] Teachers thus have an incentive to use skill-specific software that matches the curriculum goals for which they are responsible. They are deterred from exploring exciting possibilities offered by software that is not tied to a particular measurable skill, but which may provide opportunities for the student to engage in problem solving or to just "play around."

Educators have legitimate concerns regarding how the work done on the computer fits into the curriculum. They know that the bottom line is testing, and that they are held accountable for assuring that the facts of the subject matter are covered in their classroom. Therefore, although a teacher may recognize the value of seeing the students working together, cooperating, and developing creative solutions to problems offered by simulation of an historical event, this same teacher must worry about whether these students have memorized the historical facts that tests measure.

[16] Hawkins and Sheingold, op. cit., footnote 13.

TEACHER TRAINING IN TECHNOLOGY[17]

Although the State, district, and administrators set systemwide curriculum requirements, it is the teacher who determines how instructional activities are carried out. The classroom teacher looks at the time and texts at hand, slices the subject matter into daily lesson plans, and determines how to teach the required materials. If computer technology is to have an impact on teaching and learning, teachers must be comfortable with computers, seeing them as tools that enhance rather than interfere with their daily teaching. For this to happen, teachers need special training.

However, the vast majority of today's teachers have had little or no training on how to apply computers in teaching. Recent reports suggest that only about one-third of all K-12 teachers have had even 10 hours of computer training.[18] Much of that training has focused on general computer literacy, at the "introduction to computers" level, rather than on the more sophisticated and comprehensive issues of how to integrate computer technology into the curriculum or how to use the computer for a variety of teaching tasks, some of which may be entirely new. Teachers need more technology training (learning how to use computers to accomplish their current classroom goals), as well as more technology education (gaining enough knowledge about the computer and understanding of its capabilities so they can explore the potential of the computer to improve learning in nontraditional ways). OTA finds that teachers need both training and education if technology is to take hold in schools. They need to know how to work the technology to meet their goals, and how to work with it in changing goals based on what the technology makes possible.

Training and professional development, for both new and veteran classroom teachers, need to be seen as continuing efforts. Inservice education can bring the existing cadre of teachers up to speed, help them overcome computer anxieties, and guide them as they attempt to adopt powerful, multipurpose, and ever-changing technologies in the classrooms. Concurrently, it will be necessary to ensure that those entering the profession have the most up-to-date technology skills and underlying understandings. Unfortunately, the solution, like so many other answers to educational questions, is neither simple nor easily attainable.

Teacher Education Reform Efforts

The need to improve teachers' technology training and education arises at a time when reforming teacher education is receiving much attention. This comes on the heels of several years of critical review of U.S. public education. Two major reports address these reform issues and their implications for teacher

[17] Much of the work in this section is based on Allen D. Glenn and Carol A. Carrier, "A Review of the Status of Technology Training for Teachers," OTA contractor report, Sept. 22, 1987.

[18] Office of Technology Assessment, op. cit., footnote 9.

education.[19] The Holmes Group, composed of deans from large, research-oriented colleges, and the Carnegie Forum, a group of political, business, and educational leaders, each call for major changes in the preparation of teachers, higher standards for teachers, and increased professionalism, along with appropriate professional compensation.

The Holmes Group recommends that colleges abolish the undergraduate education major and move teacher education to a post-baccalaureate degree program. This would be a drastic change for almost all schools of education because, while post-baccalaureate programs have existed for years, they are the exception rather than the norm.

[19] The Holmes Group, Inc., *Tomorrow's Teachers: A Report of The Holmes Group* (East Lansing, MI: 1986); and Carnegie Forum on Education and the Economy, *A Nation Prepared: Teachers for the 21st Century*, the Report of the Task Force on Teaching as a Profession (New York, NY: May 1986).

The Carnegie Forum has set into motion a National Board for Professional Teaching Standards that will develop national examinations and guidelines for teacher certification, efforts many feel will change the profession profoundly. Concomitant efforts to reform teacher education are also occurring at the State level. More than 25 States require teacher competency testing in at least the basic skills of reading, writing, and mathematics. State regulations also specify the number of credits permitted in teacher education programs. Debate continues over how much time should be spent on content versus process in teacher education.

As a result of these calls for reform at the State and national levels, teacher education programs are changing. In the midst of these sweeping changes, technology training is not the only issue in the teacher preparation debate, but it can be one piece of the solution. The teacher reform movement provides the opportunity to consider new roles for teachers and how technology fits in.

PRESERVICE TECHNOLOGY EDUCATION

A Brief History

As the number of computers increased in elementary and secondary schools over the last 10 years, schools and colleges of education tried to respond. Many incorporated a basic computer literacy course into their curriculum, covering such topics as: "What is a computer? How does it work? How do you program it?" Proponents of programming suggested that learning to program would remove much of the mystery surrounding the operation of computers and would give teachers greater flexibility in using them.[20] Teachers would also be able to develop their own software in a period when good educational software was scarce.[21] Others found emphasis on programming reinforced the idea that only technical people—like those in the audio-visual/instructional design departments where early computer courses often originated, or those in mathematics or the sciences—could understand computers. Other teachers were often intimidated by and/or uninterested in computers,

[20] William Bramble et al., *Computers in Schools* (New York, NY: McGraw Hill, 1985), p. 225.

[21] T.J. Singletary, "Programming for Leadership," *Journal of Teacher Education*, vol. 38, No. 4, 1986, pp. 26-30.

Current Efforts To Prepare Today's New Teachers To Use Computers

Approximately 142,000 new teachers were expected to graduate in 1987-88.[22] Over 1,500 private and public institutions prepare these teachers. Their programs range in size from those with a handful of teachers to those that graduate several hundred each year. Today almost all of these teacher licensure programs provide some instruction in the use of computers.[23]

Despite course offerings, graduates of teacher preparation institutions apparently do not feel

[22] U.S. Department of Education, Office of Educational Research and Improvement, Center for Education Statistics, *The Condition of Education* (Washington, DC: 1986), p. 64. In making these projections, the National Center for Education Statistics used data from the National Education Association.

[23] 'Eighty-nine percent of all schools of education offered some form of computer training to their students. See U.S. Department of Education, Office of Educational Research and Development, *Teacher Preparation in the Use of Computers* (Washington, DC: January 1986).

prepared to use computers in teaching. The American Association of Colleges for Teacher Education recently surveyed education faculty and students in 90 member institutions offering bachelor's, master's, or doctoral programs in education. Both education faculty and students were asked to evaluate the effectiveness of their teacher education program in preparing classroom teachers. On all but 2 of the 12 aspects of teaching in the survey, more than two-thirds of both groups considered students to be prepared to assume the tasks of classroom teaching. Yet this preparation did not carry over to teaching with technology. The faculty rated only 58 percent of the students as prepared to teach with computers, while only 29 percent of the education students felt ready to teach with computers.[24] (See figure 5-1.)

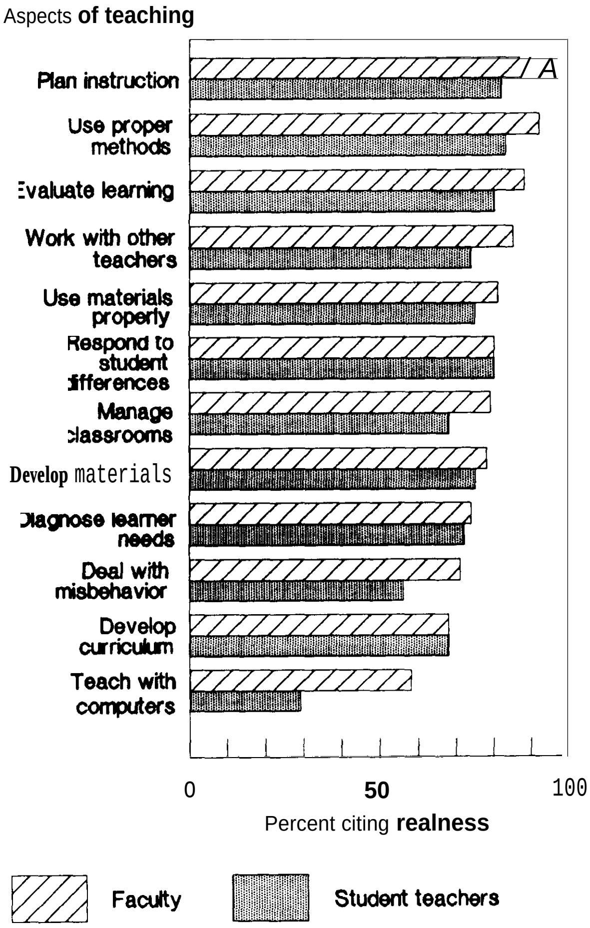
Factors Affecting Technology Training Programs

Several important changes over the past 10 years directly affect teacher technology training programs. Some have facilitated the technology training efforts, but others have created new problems that may explain why so many new teachers do not feel prepared to teach with computers.

Changing Technology.–Hardware and software have become easier to use, more powerful, and more useful in the classroom. More powerful and adaptive software means teachers have less need for programming skills. Computer training has become less technical overall. However, rapid technological change also creates problems for schools of education similar to those faced by teachers already in classrooms. As one dean at a major college of education said:

> The problem is how to prepare teachers for hardware that is not yet invented, for software that is not yet designed, and for curricula not yet imagined. It's hard to have a vision of what technology will be, but, as deans, we have to have a vision, and we have to realize that it will change.[25]

Figure 5-1.—Readiness to Teach: Perceptions of Education School Faculty and Student Teachers



SOURCE: Research About Teacher Education Project, *Teaching Facts and Figures* (Washington, DC: American Association of Colleges for Teacher Education, 1987).

Varying Student Levels of Preparation.–Schools of education are faced with students whose computer backgrounds vary considerably. Since many more high school students now have at least minimal experience with the computer, the education schools' student population is more computer literate than was the case even 5 years ago. According to one estimate, approximately 60 percent of freshman entering college today have experience using the computer." Nevertheless, some education school faculty have argued that education majors may be less pre-

[24] American Association of Colleges for Teacher Education, *Teaching Teachers: Facts and Figures* (Washington, DC: 1987).

[25] Carl Berger, Dean of the College of Education, University of Michigan, Ann Arbor, quoted in "Education and the Challenge of Technology," proceedings of a Conference on Technology and Teacher Education, sponsored by the University of California, Berkeley and Apple Computer, Inc., August 1986.

[26] Judith A. Turner, "Familiarity With New Technology Breeds Changes in Computer-Library Courses," *The Chronicle of Higher Education*, July 22,1987, pp. 9, 12.

pared to use technology than their peers in mathematics, sciences, or business majors.[27]

State Regulations and the Education Curriculum.–State departments of education and professional organizations are establishing guidelines for what technology skills teachers need. For example, the Northwest Council for Computer Education prepared guidelines for teacher education in schools of education in Washington and Oregon. (See table 5-l.) The trend at the State level is to establish preservice education requirements. Currently, 18 States and the District of Columbia *require* all students in their teaching degree programs or those seeking certification to take a course on computer topics, or require that students demonstrate familiarity in using technology for instruction.[28] An additional seven States *recommend* that some preservice training be taken.[29] This leaves half the States currently neither requiring nor recommending technology preparation for new teachers. (See figure 5-2.)

Although formal requirements may force the development of new programs of study in educational technology, establishing new programs with education school faculty whose technology expertise is uneven or limited is difficult. Furthermore, some analysts believe that schools of education are overburdened with State regulations that can minimize creativity. Some States limit the total number of credits in the teacher licensure program. In Texas, for example, a maximum of 18 credits in education courses is allowed. Such restrictions make it difficult for schools of education to develop a curriculum that meets the requirements for initial licensure and still has room for technology training, unless educational technology is introduced as a central element in both methods and theory courses. Currently, this orientation is more the exception than the norm.

Table 5-1.—General Teacher Competencies in Technology

The teacher should:
1. have an appreciation for using the computer as a tool for solving problems;
2. have the experience of using computers in the learning of subject matter;
3. have knowledge of computer vocabulary;
4. be able to use the computer as a tool (using applications such as word processing, spreadsheet analysis, or database management); and
5. be familiar with computer hardware, including the everyday operation and use of a variety of machines.

SOURCE: N. Moore, "Preparing Computer-Using Educators," *The Computer Teacher,* October 1984, pp. 48-52.

Resources in Education Schools: Hardware and Faculty Expertise.—Although today's education students may have more access to computers in their overall university coursework than did their counterparts 5 years ago, the schools and colleges of education are often behind the rest of the campus in available hardware and faculty expertise. The education school or department has seldom received the large equipment donations from hardware manufacturers that other departments have. Education faculties have usually not received systematic training in technology use.

Trying to infuse technology into the traditional methods course remains a difficult task, due to faculty reluctance and inexperience with computers.[30] One university tackled this problem by re-

[27] Gary Bitter, Arizona State University, personal communication, October 1987.

[28] "The State of California law reads as follows: "Commencing July 1, 1988, the minimum requirements for a clear teaching credential also include satisfactory completion of computer education coursework which includes general and specialized skills in the use of computers in educational settings, in accordance with regulations established by the commission.

(a) The Legislature hereby finds and declares that California's public school pupils need quality Instruction and support in the areas of computer education in order to develop the skills necessary for entry into an increasingly technological society. The legislature recognizes that computers and other technologies are an integral part of contemporary society and the state educational system.

It is the intent of the Legislature in enacting this section to provide a statewide standard for the preparation of educational personnel in the areas of computer education.

(b) For purposes of this section, "computer education" means the process of teaching pupils about computers.

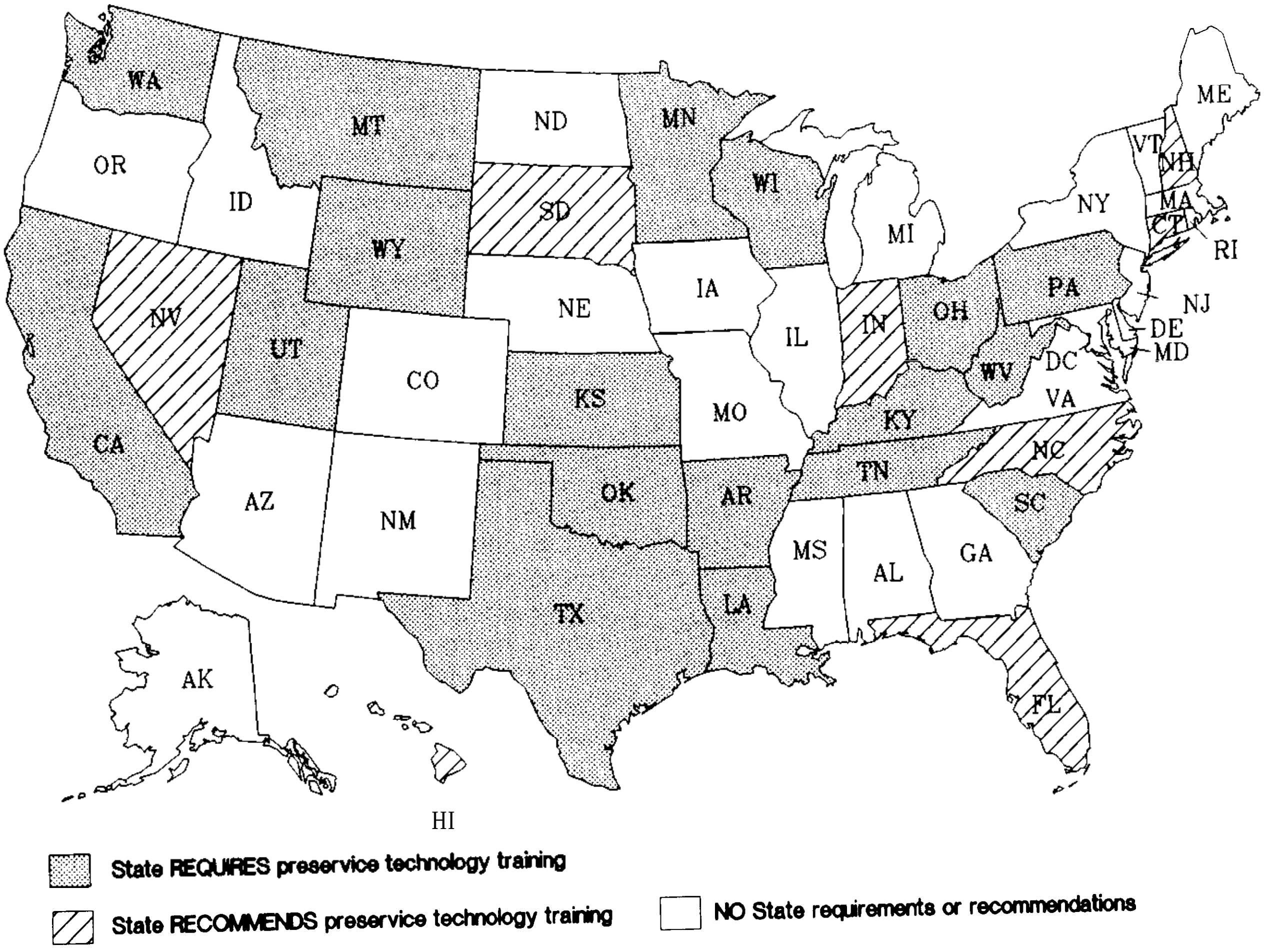
(c) The Commission on Teacher Credentialing, in consultation with the Superintendent of Public Instruction, may develop and disseminate voluntary standards for the training and performance of teachers and resource personnel in the area of computer education.

(d) The Commission on Teacher Credentialing shall study the effectiveness of the training and performance of teachers and resource personnel in the area of computer education, and shall submit a report on the results of the study to the Legislature on or before December 31, 1987. " Assembly Bill No. 1681, Sec. 44261.7 and 44276, Oct. 1, 1985.

[29] OTA State Educational Technology Survey, 1987.

[30] Presentations by Gary Bitter (Arizona State University), Larry Hannah (California State University, Sacramento), and Charlotte Scherer (Bowling Green State University) at the 1987 National Educational Computing Conference confirmed this difficulty. They maintained that it is often easier to provide a separate course on using the computer, than to convince, train, and support methods Instructors in their content courses. Education students then lack models of teaching with the computer as a tool in various curricular areas.

Figure 5-2.—State Requirements and Recommendations for Preservice Technology Programs[a]



[a]Requirements for technology training are pending or under consideration in Alabama, Colorado, Maine, and Vermont. Requirements apply only to teachers in certain subjects in Minnesota, Oklahoma, South Carolina, Tennessee, Texas, and West Virginia.

SOURCE: Office of Technology Assessment State Educational Technology Survey, 1987.

leasing a professor of education from one of her courses for 1 year. Teaming up with methods instructors in all subject matter areas to introduce computer-related activities into existing education courses, she helped out with more than 60 such class activities. She indicated that a key to the success of this program was working with the instructor to first identify an important problem or topic and then using the computer as an aid to teaching that topic. Many of the methods instructors she worked with had never used the computer in their courses. As a result of their work with this computer-using colleague, they began to explore computer applications. As confidence and expertise increased, so did the probability of use.[31] Since teachers typically teach as they were taught, upgrading the technological skills of education faculty is an essential first step for preparing technologically literate entry--level teachers.

Student Teaching Experiences:—Internships With Computer-Using Educators.–One of the most important components of teacher training, and a focus of teacher reform efforts, is the internship

[31]Betty Collins, Associate Professor of Education, University of Victoria, as cited in Glenn and Carrier, op. cit., footnote 71, p. 26.

Photo credit *Houston Independent School District*

Placing student interns with computer-using teachers can provide role models for teaching with technology.

or student teaching period. If a teacher candidate interns in a classroom where the teacher uses technology creatively and regularly, the teacher intern sees technology's promise and problems in a real-life setting. Conversely, a student teacher who comes into a classroom and develops lessons utilizing computers can help bring technology to the experienced classroom teacher who has not worked with computers previously,

Where teacher education programs arrange provide schools with technologically-rich classroom environments (such as the professional development schools advocated by the Holmes Group), student teachers can experiment with technology in instruction, Such environments could also serve as settings for experiments where student teachers collaborate with mentor teachers, teacher educators, and researchers to examine a particular technological innovation.

An interesting experiment integrating technology into the student internship program is taking place at the University of Virginia, With a $1 million equipment grant from IBM, the University's Curry School of Education set up Teacher-LINK, a computer networking system to make electronic communication available in public school classrooms where the student teachers are working. Student teachers faced with running a classroom can communicate among themselves, with their cooperating teachers, supervisors, and with faculty at the University, lessening the isolation that many teacher interns feel. Both student teachers and education faculty are excited by a resource that lets the student teachers ask questions as they occur and solve problems in the real time of the computer network. The system also supports discipline-specific computer conferences, for example, in English and social studies, These are to aid students in developing curricula and lesson plans, and in learning classroom and subject-specific skills,

One of the more practical aspects of the network is the opportunity it offers student teachers to submit lesson plans and receive feedback from their cooperating teachers and supervisors:

> While tired teachers and interns may not want to stay for several hours after school giving and responding to feedback, they may find it easier to look at lesson plans, evaluations, and project ideas in the comfort of their own homes, after they have had dinner and rested a bit. Then, if the intern prefers to work until midnight, but the cooperating teacher chooses to go to bed early and review the uploaded unit outline at 7 am, neither wakes the other, and no time is lost in leaving telephone messages.[32]

The organizers hope this experience will encourage users to develop an interest in other applications of networking, such as conferences and collaboration on curriculum development and research. The computer-networking infrastructure supports activities ranging from elementary student projects, including cross-cultural writing networks, to advanced faculty research and collaboration. ”

A computer network can also become an informal support system for beginning teachers, extending their training through the first year of teaching. Unlike doctors, who have supervised internships following medical school, beginning teachers are on their own once they graduate. Although the first year of teaching is a crucial period in teachers' development and can influence whether they stay in the profession, beginning teachers most often find themselves isolated, with few to turn to for advice.

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[32] Judi Harris, Curry School of Education, University of Virginia, Charlottesville, "Teacher-LINK: An Electronic Culture," paper presented at the annual meeting of the American Educational Research Association, New Orleans, April 1988.

[33] For a full discussion of the uses of computer networks in K-12 education, see Earl Dowdy, University of Illinois, Urbana-Champaign, "Computer Networks in Elementary and Secondary Education," OTA contractor report, October 1987.

As a means of providing first-year support to their graduates, the Harvard Graduate School of Education set up the Beginning Teacher Network. This network links 50 of Harvard's newest graduates with one another, and with several faculty members from the School of Education. They communicate through electronic mail and in forums on teaching specific subject areas, such as mathematics or psychology. Participants discuss classroom management and discipline, field concrete suggestions on the nuts and bolts of teaching, or talk about general education issues. Since the network's inception, roughly 3,400 messages have been transmitted, averaging some 110 messages a week. The participating beginning teachers, scattered across the country, value the camaraderie the network offers and the encouragement and practical information they receive from one another and from Harvard faculty. [34]

[34] Blake Rodman, " 'Hang in There, Bob': Notes for New Teachers Via Computer," *Education Week*, vol. 7, No. 32, May 4, 1988, p. 1.

INSERVICE TECHNOLOGY EDUCATION

Inservice education plays an important role in technology training for several related reasons. As cited above, most new teachers do not feel prepared to teach with computers. School systems must therefore play catch-up from the start. Furthermore, with technologies changing and applications varying so widely, it may not be either possible or desirable to expect that preservice education will ensure the effective use of technology by teachers. Just as preservice training prepares a teacher to begin teaching, so training in technology prior to entering the classroom may be best suited to providing introductory skills, enabling the new teacher to begin working with whatever technology exists in the classroom. Advanced training in applying new technologies can then occur through inservice and continuing education. Inservice training can also build on experiential learning, based on the teacher's specific classroom experience and needs. Thus, training for teachers should be seen as an ongoing requirement for professional growth.

Industry spends up to $30 billion a year on formal education to enhance and upgrade the work force. [35] Much of the teacher reform literature argues that education must make a similar effort.

Unique Characteristics of Inservice Training in Technology

Several characteristics and requirements of technology training distinguish it from other kinds of inservice training. Equipment is critical. It is possible to run an inservice session on a new reading or mathematics technique in a traditional classroom, but teaching teachers to use a word processing or gradebook program requires a computer. Furthermore, teachers can apply what they have learned in an inservice session only if they have access to the technology once the training has ended, both for gaining confidence through practice and for application in the classroom.

In addition, inservice training in technology must be sensitive to the concerns or anxieties with which teachers approach the use of technology. A teacher taking a course in other subject areas generally has some experience or background in the topic. But many teachers, especially those who consider themselves "B.C.''—before computers—have not yet worked with computers and admit to being "technophobic." Others had early negative computer training experiences. Sometimes programming was emphasized; sometimes the courses tried to cover too much, too fast[36] and had no relevance to their teaching needs. Several factors[37] contribute to a teacher's anxiety about computers; they must be taken seriously as they underlie whether or not a teacher adopts technology and how the teacher uses it in the classroom. (See box 5-E.)

[35] Anthony Carnevale, "The Learning Enterprise," *Training and Development Journal*, vol. 40, *No.* 1, January 1986, pp. 18-26.

[36] A study of teachers and administrators enrolled in a semester-long introductory course on computer applications found that for those with no prior experience, the decline in anxiety did not appear until after some 30 contact hours with the computer. See Gerald Bracey, "Still Anxiety Among Educators Over Computers," *Electronic Learning*, vol. 7, No. 6, March 1988, p. 20.

[37] See, for example, F. Williams and V. Williams, *Microcomputers in Elementary Education: Perspectives on implementation* (Belmont, CA: Wadsworth Publishing CO., 1984).

Photo credit: Paul Foldey, Lesley College

For many teachers, especially those who consider themselves "B. C." (Before Computers), learning to teach with computers is a challenge. Sensitive training, time to practice, and support from peers are the best antidotes to computer anxiety.

Factors Contributing to Effective Inservice Computer Education Programs

Studies[38] examining inservice computer education programs have identified several instructional practices that contribute to effectiveness. (See box 5-F.) In conjunction with the Minnesota Technology Demonstration Site Program, [39] part of the Minnesota legislature's educational technology initiative, a comprehensive review of inservice technology training activities was conducted. This evaluation covered 3 years (1985 to 1987) and involved 17 technology demonstration sites. Although inservice activities varied widely across the sites, evaluators found that there was a progression of inservice technology topics at most sites. These were characterized as:

- "Awareness" stage: large group workshops run to acquaint teachers with a general overview of how technologies work and to alleviate anxiety;
- "Overview" stage: workshops that delivered additional detail on how particular technologies work and usually provided examples of the application of technology to particular subject matter areas;
- "Topical" stage: a more focused approach (for example, using computers in social studies) with fewer participants;
- "Adoption/implementation" stage: more focused with intense work by each participant; and

[38] B. M. Stecher and R.S. Solorzamo, *Characteristics of Effective Computer Inservice Programs* (Pasadena, CA: Educational Testing Service, 1987).

[39] See D.L. Morehouse et al., "Technology-Related Inservice Education Findings, Issues and Recommendations: An Analysis Based on Evaluation of Minnesota's Technology Demonstration Program—Quality Evaluation and Development," a report of the Minnesota Department of Education, 1987.

Box 5-E.—First Encounters With Computers: Some Teacher Concerns

- **Fear of Uncertainty.**—Teachers have been trained to master and fully understand the tools and materials they work with in class. It requires a change in attitude to say, "I don't understand how this works, but I can see what it can do and that's enough for now." Furthermore, teachers must be in charge in their classrooms. Not being an expert may lessen the teacher's authority. Teachers have legitimate fears of embarrassing themselves in front of students who may be delighted to see that the teacher does not know everything after all.
- **Concerns Regarding Changes in Teacher/Student Relationships.**—Computers can motivate students, reinforce basic skills, keep records, focus attention, simulate environments, calculate, and give immediate feedback—all things which teachers themselves expect to do. Teachers see that students are often more enthusiastic about working with computers than with the teacher. Computers also can store considerable data and thus may "know" more than the teacher about certain things. Computers alter roles and relationships, especially when some students know more about the computer than the teacher, and when students are given responsibility for helping to run the class and for teaching other students. While some teachers welcome these opportunities to restructure the classroom and allow for peer expertise, other teachers are uncomfortable with these changes.
- **Concerns Over Accountability.**—Computers make it easier to meter productivity by centrally kept records. Student scores can be monitored and teacher success can be checked against these scores. Even sophisticated computer-using educators worry how the problem solving skills students develop with computers can be measured. As one teacher said, "For me there is a real concern that no one knows or will recognize the work I have done with students in this most important area."

SOURCE: Office of Technology Assessment, 1988.

Box 5-F.—Factors Contributing to Effective Inservice Computer Education Programs[1]

- **Appropriate balance between lecture and guided practice.**—A cycle of minipresentations, demonstrations, and practice sessions appeared to be the most effective approach.
- **Detailed curriculum guides and lesson plans.**—Well-planned materials were a visible component of the inservice programs.
- **Clear and relevant objectives.**—Teachers needed to feel they had a clear understanding of what they would learn and of their responsibilities.
- **Lesson-related materials and handouts.**—Such materials appeared to free teachers from extensive notetaking or reliance on computer manuals.
- **Inservice lessons linked to instruction.**—Teachers liked specific help on preparing materials and experiences for their own students, things they could go back and use with their students the next day. Teachers appreciated and learned from good modeling on the part of the trainers.
- **Peer interaction.**—Communication among participants during hands-on sessions was particularly effective.
- **Strategies for teaching heterogeneous classes.**—Trainers who had ways to deal with students of differing levels of prior knowledge and anxiety were more effective. For example, some trainers used teaching assistants effectively in helping less or more advanced students.
- **Followup.**—The impact of training was much stronger when followed up. Typically, teachers would come back together and report on their use of the computer application in the classroom, and share experiences.

[1]B.M. Stechner and R.S. Solorzano, *Characteristics of Effective Computer Inservice Programs* (Pasadena, CA: Educational Testing Service, 1987).

- "Integration" stage: characterized by fine tuning of curriculum materials that use technology or guided assistance in integrating certain types of technology into a teacher's lesson.

Teachers reported that they preferred learning about technology from other teachers or those who understand the settings in which they work (including the limitations and constraints of those settings). The teachers said they wanted access to followup support, and access to equipment and software during and after the inservice training. Seventy-eight percent reported that they participated because they were curious, had specifically requested the topic, or preferred a technology-related topic to other nontechnology inservice courses that were available. Nearly 80 percent of the teachers in the study said that they had used the training application in their classrooms.

Interviews with technology site directors or district superintendents indicated they believed strongly that teachers should be involved in the planning of technology inservice activities and that such activities must be based on teachers' needs.

The evaluators concluded that, for inservice education to be a powerful force in moving technology into classrooms, it must have a strong practice or "hands on" component, must be taught by credible sources (most notably other teachers), must be suited to the competence level of the teachers, must include followup support and guidance, must be sufficiently long, and should include extensive instruction in the use of computer software tool applications.

State and Local Efforts

The local school district is the key provider of all inservice training for teachers, and this role carries over to inservice training in the use of technology. Districts use a variety of course providers, differing approaches, and funding sources. Although the State and / or the Federal Government may provide some funding for inservice training, the district decides who will be trained, how, and where. Providers may include local universities, regional resource centers, intermediate school districts, local technology departments, hardware companies, software developers, and professional organizations. The training can be formal or informal, long term or just a few hours, ranging from a full program of studies (encompassing a number of courses leading to an advanced degree or special certificate), to short courses on a particular software tool, attendance at a technology conference, or teacher-to-teacher sharing right in the classroom. The technology can be both the focus of training and the training source, as happens with electronic bulletin boards, computer conferencing, and courses broadcast via satellite from distant locations. Local district monies constitute the principal source of funding, with commitments of State and Federal resources also targeted to teacher training activities.

States play a significant role in furthering the effective use of technology. In identifying the challenges and issues critical to technology in schools, the National Governors' Association recommended: ". . . that at least 10 to 20 percent of State funds allocated for acquisition of various machines should go for training programs. The task force strongly believes that States must make a greater commitment to support training programs."[40] While State support has already been a significant factor in the growing use of technology, it is likely to be even more so in the future. State influence emanates from direct and indirect funding, technical assistance, institutional arrangements, and regulations or recommendations.

OTA's State Educational Technology Survey found that 41 States have a Technology Coordinator or an Office of Technology. Thirty-three States and the District of Columbia provide some funding for teacher training in technology. This support comes from State funds earmarked specifically for technology training in over half of these cases, but States may also use their general State aid to education, professional development funds, monies funneled to regional centers, or training funds which the State has received from special Federal programs, such as Title II funding for mathematics and science teacher training, Chapter 1, Chapter 2, Vocational Education, or Special Education monies.[41] One estimate for State spending for teacher training in technology showed an increase from $10 million in 21 States in 1986 to a total of $25 million in 25 States in 1987.[42]

In the OTA survey, States reported wide variations in funding—from as little as $20,000 to a high of$15 million per year (see appendix A). Most States have, however, been unable to allocate the level of financial support for teacher training in technology that they would prefer. Those which do not directly support training from State funds find other ways to assist teachers to use technology, as, for example, in their software evaluation centers or State purchase plans for hardware and software that make

*'National Governors' Association, Center for Policy Research and Analysis, *Time for Results: The Governors' 1991 Report on Education* (Washington, DC: 1986), p. 132.

[41]OTA state Educational Technology Survey, 1987.

[42]*Electronic Learning*, "Educational Technology 1987, " vol. 7, No. 2, October 1987, p. 39.

it possible for teachers to purchase materials at reduced cost. Many States run annual technology conferences, while others put on workshops or support regional training efforts. California was an early initiator of the concept of regional Technology Education Computer (TEC) Centers, to provide a network of resources for training and technical assistance all across the State. California's TEC Centers provided a structure for coordinating services and resources. Although these centers played a major support role, their State funding was eliminated in the 1987 budget by the Governor. Some TEC Centers have continued with reduced funding, most of it provided by local districts or other non-State support.

In contrast, New York State's Teacher Resource and Computer Training Centers have expanded dramatically. In 1984, the New York State legislature created a network of regional teacher resource and computer training centers to improve teaching skills and train teachers in the educational applications of computer technology. Teacher organizations have been instrumental in setting up the centers, most of which are housed in local schools, and teachers chose the special focus on technology training. In 1987, the State legislature voted to increase funding for the centers from $12.5 million to $15 million, in order to support the existing 74 centers and add 17 new centers. The centers are linked electronically, enabling the teachers in one center to communicate with teachers in other centers, either informally on electronic bulletin boards, or more formally in computer conferences organized by the teachers on topics of shared concern (for example, dropout prevention strategies).[43]

Most States recommend that all teachers participate in inservice courses on teaching with technology; three require it. (See figure 5-3.) Minnesota requires that every teacher in the State take at least one computer-related course and West Virginia requires that teachers in certain academic disciples take a computer course. In Utah, all current teachers must demonstrate the ability to use technology in instruction. Other ways to encourage teachers to use technology include the unusual approach taken by the State of New Hampshire. The State provided 1,950 teachers with a personal computer of their own to use at home for 3 years. With the computer they received software and training to enhance their personal productivity. The State is gambling on the fact that, as teachers become comfortable with computers by using them at home, they will see ways of applying them to their teaching and adopt technology as a teaching tool with enthusiasm and a measure of expertise.

District Activities

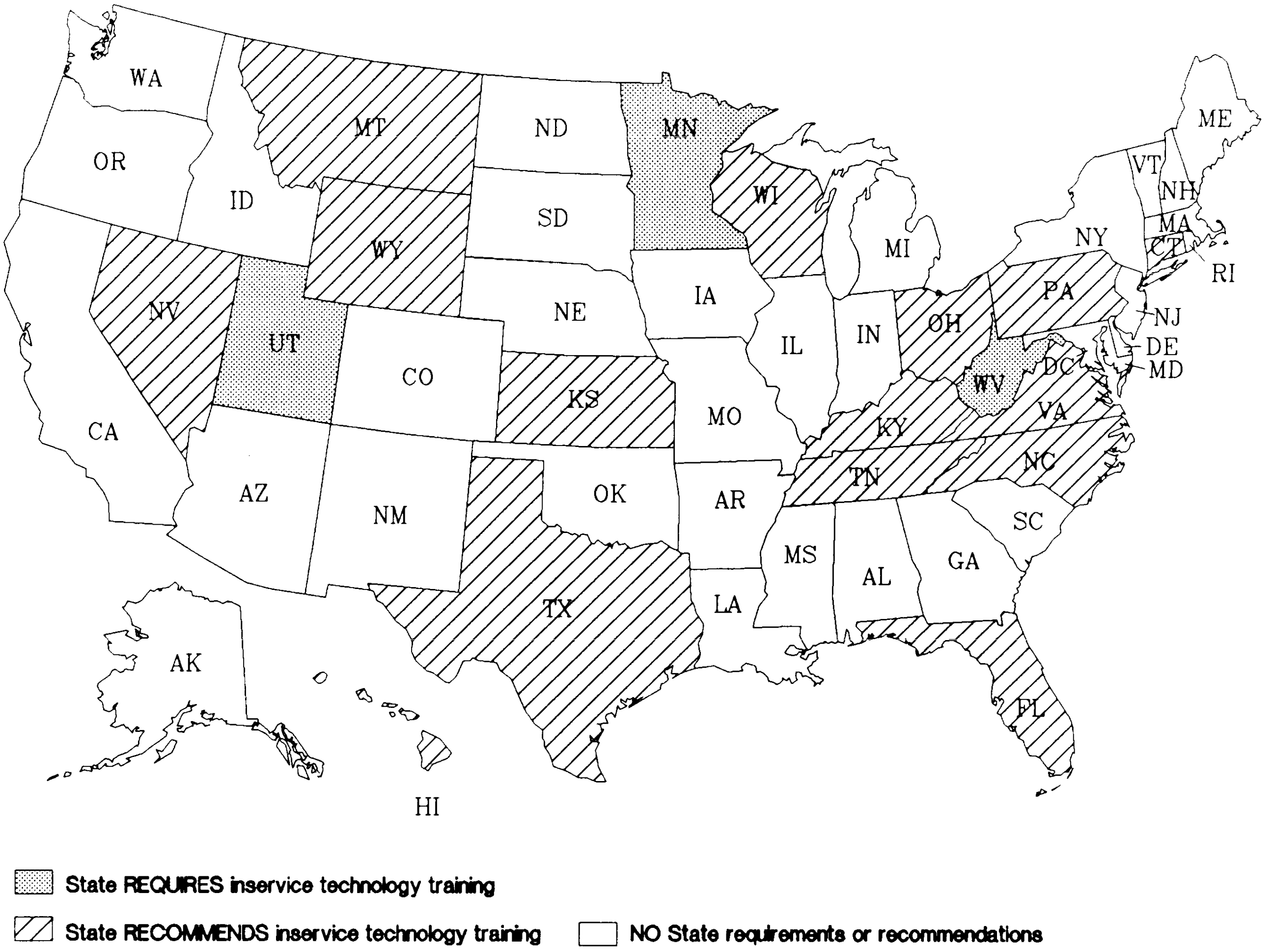
While States play a large and growing role in providing inservice technology training, the major source of such training is the school district. The most consistent professional education experience for a teacher is the inservice program sponsored by the district. At least once during each year all teachers attend some type of inservice workshop on a topic of their choosing or of the district's sponsorship. Although considerable resources have been allocated to inservice training in technology, it is difficult to estimate the overall level of funding support since districts may not separate technology

Photo **credit:** *Computer Learning Month*

Some of the most effective teacher training comes through support from more experienced teachers in informal sessions where new strategies can be practiced before use in the classroom, as seen here at the Packer School, Brooklyn, New York.

[43] In addition to these centers, many of the State Intermediate units and teacher training Institutions not funded as teacher resource and computer training centers also offer programs of technology training.

Figure 5-3.—State Requirements and Recommendations for Inservice Technology Programs[a]



[a]Requirements for technology training are pending or under consideration in Alabama, Colorado, Maine, and Vermont. Only teachers of certain subjects are required to take a computer course in West Virginia.

SOURCE: Office of Technology Assessment, State Educational Technology Survey, 1987.

courses from overall professional development support.

In a series of OTA case studies[44] of various approaches to technology training for teachers, three school districts were studied (Houston Independent School District in Texas, Albuquerque Public Schools in New Mexico, and Jefferson County, Alabama). In each of these districts, teacher training was a central part of the technology implementation plans.

Regarded as one of the Nation's leading districts in educational technology, the Houston Independent School District (HISD) established the first Department of Technology for a local school system in 1982. The goal was to assure that all technology planning and services to HISD schools would be centralized and coordinated. As a part of this broad effort, the position of Teacher Technologist was created. Each of the 240 teachers who entered the program received 296 hours of technology training conducted by the department. To qualify for a $2,000 bonus, they take an additional 30 hours of updated training each year. The Teacher Technologists serve 90 percent of Houston's schools, and spend 60 per-

[44]For a discussion of seven case studies of State, county, district, school level, and industry supported teacher training, see John Strange et al., "Alternative Approaches to Developing a Cadre of Teacher Technologists," OTA contractor report, December 1987.

cent of their time in the classroom, teaching the State-mandated computer course or helping to integrate technology in other content areas. Additional school-wide duties include training other teachers, parents, and administrators; running student computer clubs and other activities; and coordinating purchases and allocation of hardware, software, and resource materials. The centralized approach to Houston's technology program is currently being reevaluated under a new superintendent. HISD's 1986-87 technology budget excluding hardware appropriations was $2.3 million, a 70 percent reduction from that of the previous year, when $7.7 million was made available.

Albuquerque adopted a less centralized training approach. The district established a partnership with two local institutions of higher education to provide a 64-hour course sequence for interested teachers. The training program, Computing for Teachers, focuses on mastery of three core applications: word processing, database management, and LOGO, with emphasis on developing strategies for integrating technologies across the K-12 curriculum. The course sequence can be taken for credit at the University of New Mexico at the teacher's expense, or at the Technical-Vocational Institute, where the fee is paid by the district at a cost of $5 per trainee. Both courses use the same materials and teachers from the Albuquerque Public School staff. Approximately 75 percent of the teachers in the system have completed this computer training cycle.

The Jefferson County study provided a very different model, involving limited local funding but substantial support from local businesses and national hardware and software companies. An ambitious multimedia training program involved after-school workshops and continuing support from the county's Office of Staff Development. The goals of the program were to help teachers and students (who were allowed to participate in the workshops) incorporate a variety of technologies (radio, TV, desktop publishing, video, electronic keyboards, and telecommunications) into classroom presentations across a range of curricular areas; to provide hands-on experience in creating media; and to teach media production as a critical thinking process. Approximately 100 teachers from 13 county schools participated during the 1986-87 school year. All training was conducted by the program's initiator who received $5,000 for the 9-month project from Title II funds committed by the Jefferson County School District. Because he volunteered the rest of his time to the project, and the teachers attended the training voluntarily on their own time, no other school system funding was involved. National and local corporate sponsors donated equipment, software, and other materials valued at more than $50,000. Other local sponsors, such as the Alabama Power Co., contributed space and support for multimedia fairs that showcase teacher- and student-created materials.

While these three examples show the range and variety of local district approaches, there is no one best model which school districts adopt in the scramble to keep pace with technology.

Training From Other Sources

Computer companies, software developers, and professional organizations also provide training and support for teachers to use computers in their curriculum. On a more informal basis, classroom teachers give each other assistance and support, sometimes through informal peer assistance in the school, as well as across town or across the continent via the technology itself when teachers participate in networking activities such as electronic mail, information sharing via electronic bulletin boards, computer conferencing, and subject-oriented workshops. Sometimes schools even set up systems where students with computer expertise tutor teachers.

Industry Efforts

Computer companies have a direct economic interest in training. It makes good business sense to instill in teachers a sense of loyalty to a particular type of computer. Training efforts therefore are seen as one cost of selling computers.

An early entrant to the training arena was the Tandy Corp., which introduced many teachers to computers through seminars and workshops in Radio Shack outlets. Early efforts reached more than 400,000 teachers. Tandy currently offers training both at the school site and in Tandy training centers, providing custom workshops to meet the needs of individual districts or State agencies that are working closely with Tandy.[45]

[45]William Gattis, vice president, Radio Shack Education Division, personal communication, Feb. 22, 1988.

One comprehensive effort at computer training for educators was the 1984 joint venture between the National Computer Training Institute of Fremont, California, and IBM to provide training on the IBM PC Jr. (See box 5-G.) Particularly far-sighted was their concept of giving teachers a computer of their own for home use, enabling the teacher to feel comfortable through gradual mastery, and eventually to appreciate the computer as a tool that could also be applied at school, Many of the major computer companies active in the K-12 market have now instituted educators' discount programs.

IBM has also participated in college and university discount programs by making computers and related technology available at reduced prices. As noted above, IBM is supporting demonstrations of telecommunications networks for student teachers (University of Virginia's Teacher-LINK) and first year teachers (Harvard's Graduate School of Education's Beginning Teacher Program). IBM also provides implementation workshops for school districts that have purchased IBM software, and has conducted extensive teacher training efforts for districts that have implemented the *Writing to Read* pro-

Box 5-G.—IBM/National Computer Training Institute Cooperative Training Plan

In August 1984,97 pairs of trainers from 49 States and the District of Columbia, chosen for their experience in using computers, were brought to the University of California at Berkeley for 2 weeks of intensive training at IBM's expense. The training emphasized the use of the IBM PC Jr. and applications including four components of the IBM Assistant Series of administrative programs (word processing, report writing, database development and management, and graphing), *Multiplan,* BASIC, LOGO, telecommunications, and software evaluation. In return for the commitment of 2 weeks training, IBM provided each school's pair of trainers with 17 IBM PC Juniors, monitors, graphic printers, software, modems, carrying cases, and a variety of additional peripherals. The sponsoring schools agreed to provide a secure, air-conditioned laboratory for 15 sets of the equipment, to use the laboratories for computer-related instruction during the school day, and to make the laboratories available to teachers for evenings, weekends, and summer training sessions. The two participating teachers were each given a PC, monitor, and printer for their own use at home. In attempting to take a bite into Apple's growing share of the K-12 market, IBM was willing to invest a substantial sum. Estimates for the hardware and software alone were $3 million. The cost of the Z-week training session, borne by IBM and the National Computer Training Institute (NCTI), was at least another $60,000. The goal was to have these school sites serve as models for their local area and to encourage other schools to purchase the PC Jr.

There was to be a second stage to the initiative, which called for IBM. to market the PC Jr. to teachers and educators for their personal use at a very low-price, perhaps as little as $500 per system. With each system, a teacher would receive two coupons, one good for 7 free hours of training in personal computing at one of the NCTI sites, and the other worth a substantial rebate on the 40-hour NCTI course designed specifically for classroom teachers. The theory was that, in order to get teachers to use computers in the classroom, teachers first had to become familiar, competent, and comfortable with the hardware and software by having computers in their homes.

The second stage never got off the ground, and NCTI went out of business in September 1985. Several reasons have been suggested for NCTI's failure, including NCTI inexperience in dealing with the school market and the competition from computer courses offered for credit at local colleges, sometimes at a lower cost than the noncredit NCTI course. Other problems included difficulties with the PC Jr. keyboard, the PC-DOS operating system which required a complex form of loading and disc swapping, and lack of software for the PC Jr. Additional problems included IBM's legal concerns over the potential for an unfair trade practices suit if the PC Jr. were to be sold to teachers at the proposed below market cost of $500. Potential buyers were also frightened off by the persistent rumors, eventually substantiated, that the PC Jr. would be withdrawn from the market. The program suffered a final tragic loss on August 2, 1985 when Phil Estridge, the IBM executive most responsible for the IBM/NCTl initiative, was killed in a plane crash, With his death, support for the program ended altogether.

SOURCE: Office of Technology Assessment, 1987. For a fuller description of this and other case studies of teachers training see John Strange et al., "Alternative Approaches to Developing a Cadre of Teacher Technologists," OTA contractor report, December 1987.

gram. IBM has also provided equipment for use at technology demonstration centers.

Apple has supported teacher training efforts through a variety of company policies. To meet the needs of districts who want training from a vendor, Apple has typically contracted with private corporations and consultants to provide teacher workshops. For example, Apple has contracted with the Minnesota Education Computing Corp. (MECC) to provide workshops to school districts. This cooperative relationship has worked because benefits accrue to each of the parties involved. Apple has resources to subsidize some of the cost; MECC has the expertise to design, and trainers to conduct, the workshops; and the district provides facilities and release time for the teachers as well as some of the training cost.[46]

Computer companies are also supporting education through advisory groups made up of experts from education and industry who meet to discuss education and technology. For example, Apple's Education Advisory Council held a meeting in November 1985 focusing on teacher and administrator training. This was followed in August 1986 by a gathering of 90 deans of education schools, directors of teacher education, researchers, and industry experts to discuss technology and teacher education. One of the recommendations stemming from the Conference on Technology and Teacher Education—to establish partnerships among universities, industry, and schools to respond to the challenge of technology in education—has taken root in the efforts of several hardware manufacturers. The Apple University Consortium, which links 32 institutions of higher education for information sharing and provides large discounts on equipment, has been particularly beneficial to schools of education as they set up computer laboratories.

American Telephone and Telegraph (AT&T), a recent entry onto the education scene, has developed a cooperative relationship with Indiana University's School of Education. AT&T provides equipment and technical support for the reconfiguration of the school's technology program. AT&T will provide funds for the retraining of the faculty and for the development of educational programs for both undergraduates and graduates in education. This arrangement will give Indiana's School of Education both the latest technology from AT&T and the funding needed to utilize equipment effectively in redesigning the curriculum.

Software Developers Training Efforts

Education software developers are also interested in helping teachers use the technology, especially to encourage teachers to use the software sold by their own company. This training, too, can take many forms. The most basic gives guidance on how to use software packages in the curriculum and is similar to the printed manuals teachers receive with a new textbook series. For example, in a series of software packages for simulations based on historical and contemporary issues, each program package includes a teacher's guide with reproducible materials, detailed lesson plans, and individual reference books. The materials are designed to help the teacher use the simulations in a way that gets the most out of the software, while making it easier for the teacher to integrate the materials into the curriculum.[47]

Other software producers make videotapes available to assist teachers to use their products. For example, Sunburst Communications has developed videotapes to illustrate how a teacher might use its products, many of which involve problem solving activities and are more complex to use than traditional drill and practice programs. The tapes show actual classroom applications and provide clues to the teacher on how to organize the students and how to proceed through the lessons. The materials can be used by an individual teacher, by district training personnel for group inservice activities, or by the software sales representative in providing inservice education.

Some software developers give away free software after teachers have attended a course on how to use that software in the curriculum. Other developers (for example, Mindscape, Inc.) are providing work-

[46]Minnesota Education Computing Corp. estimates that it costs $200 to $300 per day, per teacher to conduct its training. School districts at most are willing to pay $100 to $150 per day. Because vendors like Apple stand to gain from teachers being trained to use their machines, vendors are willing to subsidize some of the cost of the training, thus reducing costs to the district. Don Rawitsch, Minnesota Education Computing Corp., personal communication, 1987.

[47]Tom Synder Productions, Cambridge, MA, *Decisions Decisions Series* (Software series, 1986).

shops on computer applications in content areas (social studies, writing, and mathematics), using a variety of software, not just their own brands. They are gambling that, with increased training, teachers will become more informed and enthusiastic users of computers. This enthusiasm would then pay off in increased software sales, including sales of their company's titles.

As more and more teachers use technology, hardware and software companies may want to consider joint efforts with State education agencies, regional teacher resource providers, and universities to develop workable strategies to meet the needs of training teachers in emerging technology applications. Substantial efforts will be required in the short term and over the long term to accomplish technology integration across the curriculum. It is clear that each training provider has limited resources; there may be ways to combine these resources more efficiently and effectively.

Informal Training Via Computer Networks[48]

Elementary and secondary schools are also beginning to make use of the communications capabilities of computers for electronic mail, information retrieval, and computer conferencing. With an investment of $2,000 or less, a school can participate in using a network, assuming that the school already has a telephone line. Costs vary over time depending on the types of activities in which the school participates, long-distance charges for hookup, and subscriptions to various services. These costs are proportional to usage and largely under the control of school administrators.

While State, local, district, and commercial networks are proliferating, it is difficult to estimate how many teachers and students use them. Potentially thousands of elementary and secondary schools and millions of students could engage in joint activities using computer networking. Moreover, teachers and administrators could share information across, as well as within, the traditional institutional boundaries. This opens up significant new opportunities for collaboration, research, and information sharing. Barriers of geographic isolation, socioeconomic status, and physical handicaps can be overcome.

Electronic networks can help to solve one of the most basic problems in K-12 teaching: the isolation of the classroom teacher. Discussions and sharing of curriculum ideas, materials, and methods are facilitated by the immediacy of the network. For the elementary school teacher in particular, who spends all day, every day, in a classroom with children, the opportunity to reach other professionals outside the four walls of the classroom can be liberating and stimulating. Whether the novelty of this effect will wear off with experience is debatable; nonetheless, it is hard to envision teachers closing the windows to a wider world once they have been opened through electronic networking. The capabilities of networks are just beginning to be explored by teachers. Box 5-H shows an informal computer conference initiated by one teacher looking for ideas and curriculum support from other teachers, an example of what can be done by innovative teachers hooking up via telecommunications.

Other Informal Sources of Peer Support

While the modem can connect teachers in different schools, the computer itself can help teachers within a school work cooperatively. Perhaps because of the computer's novelty, many teachers feel comfortable asking other teachers for help with computer applications, even though teachers do not so readily ask peers for help with normal course work.

Much is to be gained when teachers open their classroom doors to the enrichment other teachers offer. In some cases, this can be formalized. Over a 5-year period, every secondary teacher in Pitts--burgh's Schenley High School spends an 8-week "sabbatical" working with master teachers at the school.[49] The National Education Association has employed the concept of teachers teaming together in their new Christa McAuliff Institute for Educational Pioneering. The 20 teachers chosen for the first Institute were selected on the basis of applications suggesting uses of new technologies in the classroom. Each application had to be submitted by a two to four member team, who will work together on their proposed technology application at their home school.

[48]For further discussion, see Dowdy, op. cit., footnote 33.

[49]Robert Pearlman, Boston Latin School, Boston, MA, personal communication, December 1987.

Box 5-H.—Excerpts From a Computer Conference on the MIX Network: "The National Student Book Search"[1]

The following message was sent via the MIX Computer Conference, "The National Student Book Search," to interested parties. The conference was initiated by Steven Pinney, a teacher.

> The variety of favorite classroom literature can be explored by the building of a national literature database. This project's focus is the use of both cooperative learning and critical thinking skills as they apply to the literature read daily in America's classrooms. . . . The focus of this project is the answer to this question:
>
> *What piece of literature does your class feel is their favorite?*
>
> The answer to this question will be sent to MIX via a format similar to a computer software database and incorporate information on the school, the students, and the literature selected.
>
> If you have writing/thinking activities that you feel would be of interest to other teachers in this project, please offer them in **2.Suggestions**. s.pinney

response: from t.evans:

Don't they have to read an awful lot of books to make their choice valid? Our school is going to a thematic approach to learning as well as a totally literature based program. . . . We first coordinate our science and social studies curriculum—then select novels to fit the theme we are teaching—to do a really good job of teaching a novel takes several weeks . . . but at 5th grade it is hard for many to sit still and read.

> response from s.pinney:
>
> Welcome, t.evans . . . and I agree it is a REAL challenge to support so much reading, but I have found that many teachers are not as fortunate as you to have such dedicated cooperation as you have mentioned. I, for instance, work without the option to do such exciting planning and feel the worse for it. What HAS worked in this project, though, is to set the problem up as a class project that we work TOWARD . . . thus we are now forming groups to read say 5 or 6 different books and present their findings to us all so we may begin to narrow the field. By November we hope to have a candidate list of maybe 10 suggested good books to regroup, reread and narrow to 5 . . . and so on. Does this help at all?

response from r.conner:

Steven: My timeline . . . will have to be mid-January. Will that still meet and mesh with your timeline? Count me in, if so.

> response from s.pinney:
>
> Welcome Raleigh: My timeline is poured in jello as I teach 7th grade and with plays, track meets, the flu, makeup work and ski trips I have a heck of a time committing to anything firm. We plan . . . to build a database of general categories and comment areas and then we will get to work. January sounds refreshingly sane! Let's do it! Steven.

response from k.yalda

Hi Steven: I popped in to see what this conference was about. It sounds great and definitely worthwhile. But at the risk of exposing my ignorance, I'm not sure I understand just what the project IS. Is "great books" just a phrase you're using, or are you referring to the classics in literature? could you explain the project a little more thoroughly for us slow learners? Thanks, Kim.

(and so on.)

[1]McGraw-Hill, Inc., Eden Prairie, MN, MIX, The McGraw-Hill Information Exchange for Educators.

POLICY IMPLICATIONS

Clearly, the teacher is central to full development of technology use in education. Teachers are not the problem, and without them there can be no solution. Most teachers want to use technology, but few have found ways to exploit its full potential. The technology will not be used, and certainly not used well, unless teachers are trained in the use of the technology, provided goals for new applications, supported in doing so, and rewarded for their successes in meeting these goals.

OTA finds that there are players on many fronts who have a stake in providing what teachers need now and in the future, and new technologies themselves can become tools for training and support.

Teacher Education: A Place to Begin

Training in the use of technology will need to be a part of the preparation every entry-level teacher receives. Several factors explain why this training need has not been met: lack of expertise of many education school faculty; insufficient and outdated technology resources; and incomplete understanding and attention to how teaching roles may change as technology changes the teaching environment. Preservice technology support will need to address a number of factors.

Training for Education School Faculty.– Courses or workshops can bring college of education faculty up to speed in current applications of computer technology in education. Possible sponsors include: Federal agencies, through programs such as the Department of Education's Fund for Improvement of Postsecondary Education, or the National Science Foundation; State Departments of Education; professional associations such as the American Association of Colleges for Teacher Education and the National Council for Accreditation of Teacher Education; or industry,

Equipment.–Because of the costs of maintaining up-to-date equipment and software, schools of education will need help from both the private sector and the Federal Government. Improved computer facilities in schools and colleges of education may require Federal support comparable to ongoing Federal support for supplying the most up-to-date facilities in university science laboratories. In addition, special institutional arrangements could be made with industry similar to the support provided to other academic departments in the university. Just as industry has encouraged familiarity with and loyalty to hardware brands and software packages among undergraduates and graduates going into science and business, so too will they benefit from supporting education students' use of their hardware and soft ware as a tool they will expect to use in teaching.

Undergraduate Competencies.–Schools of education need to cooperate with the college or university at large to establish basic levels of technological competencies for students. A substantial portion of the undergraduate program for teaching majors takes place outside the school of education. There may be university resources that can contribute to students' understanding and competence with technology. At the same time, inappropriate or negative experiences with technology can create barriers to future use in education. How best to nurture computer-using educators can be addressed in a variety of ways, at different institutions.

Teaching Internships.—Schools of education and the local school systems they serve could work together to develop teacher internships on the model of teaching hospitals. These settings make it possible to test and apply state-of-the-art technologies by the new practitioner under assistance of the experienced teacher. The school provides the real-world setting for the prospective teachers, and they in turn can bring to the classroom the most up-to-date information on educational technologies and their applications. Experimental schools could also provide research internships for both prospective teachers and education researchers.

Research and Pilot Projects.–Schools of education could be in the forefront of research on how to effectively prepare technologically literate teachers and how to upgrade their skills. Currently, the research base in teacher technology education is very weak. Federal programs can stimulate a wide range of activities, targeting funds for various programs and areas of the curriculum, for example, science and mathematics education, education of at-risk students, and special education. In supporting a number of technology demonstrations, States can provide incentives for local districts to work directly with university educators and private industry.

Keeping Up With Technology: Inservice and Informal Training

Training in the use of computers and other technologies should be continued throughout a teacher's career. If teachers are to move from the simple use of technology to more integrated instructional approaches, innovative inservice programs accompanied by followup support will be needed. Recommended components include the following:

Incentives.–A wider range of incentives will be needed to encourage teachers to learn about and use technology. School boards have traditionally encouraged teachers to gain new skills by providing higher pay for advanced degrees. However, more than half of all teachers in primary and secondary schools already hold a master's degree or higher, so this traditional approach will not be enough. Additional incentives could be developed to encourage teachers to stretch beyond their current levels of expertise or to encourage technologically experienced teachers to train their colleagues and provide support for them. Extending the teacher-to-teacher connection is a strategy that could bring dividends on all sides. A wide range of options is possible:

- summer employment;
- release time during the school day;
- additional pay for technological expertise;
- a computer for every teacher to use at home or at school;
- grants for software acquisition for the classroom;
- sabbaticals with universities, hardware manufacturers, and software developers to conduct research or provide advice regarding educational applications;
- paid participation in professional conferences; and
- increased status as master teachers or lead teachers in the school, with corresponding authority and remuneration.

Incentives are important means of holding trained teachers in the school systems that have invested in their technology skills. These individuals are in great demand, and higher paying positions in other school systems or in the private sector may drain the best teachers if extra support is not provided.

Communications.– With technology changing and expanding rapidly, there is a clear need for the Federal Government to assume a broader role in disseminating educational technology information to teachers across the Nation. Technology can be a medium for communications. While a variety of computer networks have been set up by some districts or States, none has a national perspective. A central clearinghouse or collection of regional networks would be a useful way to disseminate information about research, models, and innovative or advanced approaches to technology use and training. Because there is now no central clearinghouse, redundancy occurs, common mistakes are repeated, and few learn from the work of others.

School districts can make up-to-date telecommunications accessible to their staff. Electronic networks could be supported, by installing phone lines in classrooms or laboratories, and by subsidizing subscriptions and connect costs on bulletin board systems, databases, and other resources which can keep teachers informed and in communication with their colleagues and experts around the country. Telecourses and other distance learning options for teachers (as well as students) are other mechanisms to make information available.

As use of telecommunications networks expands, the question of costs will become a critical factor. There may be a need to examine ways to subsidize or provide reduced rates for educational use.

Models and Pilot Projects.–The Federal Government could support projects that are models of technology training for States and districts or institutions of higher education. Principals of effective technology training, at the inservice level especially, have been identified and confirmed by research. But while these principles seem solid, the research base to guide decisionmaking about technology training must be expanded. Several educational institutions have developed technology education programs that attract teachers from across the Nation.[50] These efforts provide a rich source of expertise for further development.

Federal Leadership

The Federal Government, particularly the Department of Education, could provide an important leadership role. Technology initiatives begun in the early 1980s have all but disappeared. Many of the pioneering computer-using educators were originally trained through direct Federal support via summer institutes or special courses offered by the National Science Foundation (NSF) or Department of Education. Precollege Teacher Development in Science programs were eliminated by the zero funding of the

[50] See Lesley College case study in Strange et al., op. cit., footnote 44.

Science Education Directorate (part of NSF) in 1982 and the elimination of categorical grant programs with the Educational Consolidation and Improvement Act (ECIA) of 1982. Although the Education for Economic Security Act (EESA) provides support of teacher training in mathematics, science, critical foreign languages, and computer learning, most efforts have focused on mathematics and science. Teacher efforts at NSF have also focused on applications in mathematics and science, leaving humanities teachers without Federal training support. If these NSF efforts were expanded to include all types of teacher training that utilizes technology, much greater funding would be required for the Teacher Enhancement Program,

Yet States and districts continued to support teacher training in technology on their own, channeling their ECIA or EESA block grant funds into the purchase of hardware and software and teacher training in their applications. They have also provided extensive financial support for these activities under their State and local operating budgets. As a result, there is much activity, but it is highly varied in size and scope from State-to-State and district-to-district within States. A national need is being handled as 16,000 local problems.

A primary role of the Federal Government can be to provide a vision for teachers, encouraging them to look beyond today's classroom computer activities, small but exciting though the changes may be, and to scan the horizon for tomorrow's potential. If technology can offer opportunities for fundamental changes in how children learn, in how schooling is organized, and how teachers function, it is important that this vision be elucidated, not only by the hardware manufacturers in double page advertisements in popular magazines or on commercials during the Super Bowl, but by the Federal Government, including the Secretary of Education,

Chapter 6

Software: Quantity, Quality, and the Marketplace

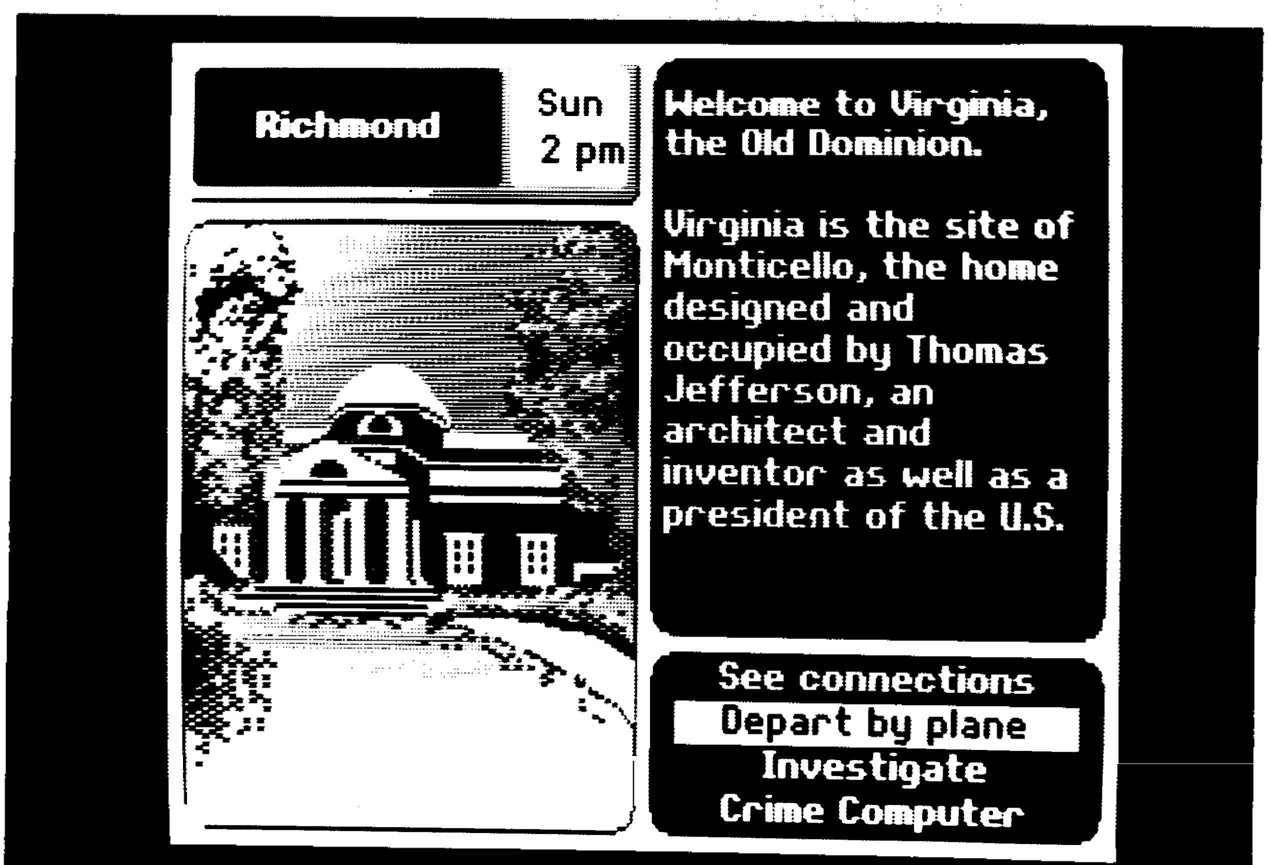


Photo credit: Broderbund Software

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Chapter 6

Software: Quantity, Quality, and the Marketplace

INTRODUCTION

Since its first printed appearance in a technical computing journal in 1960, the word software has evolved into a familiar part of the English vernacular. It is now commonly used for technologies that predate computers, as a metaphor to distinguish machines from people or their attitudes,[2] as well as for codified instructions that make the computer's electronic circuitry responsive to decisionmaking, information gathering, and data processing tasks.

Because the computer is a technology for collecting, organizing, analyzing, and communicating information, it might be argued that all software is educational.[3] Business persons who calculate profits, losses, and market positions; military analysts concerned with logistics; physicians who view three dimensional images of the human anatomy; econometricians who forecast inflation and unemployment; writers who create and revise poetry and prose; children who use computers at home to play chess or Pac Man; cognitive psychologists who attempt to simulate brain behavior; and research scientists who model the movement of subatomic particles—all can be said to be *learning.*

The term educational software, then, which is fast entering the popular lexicon, can refer to a broad category of programs: generic computational, word processing, data management, industrial design, games, and communications tools originally designed for business, science, and industry; training programs that are cost-effective supplements or substitutes for classroom training in business and the military; as well as didactic or instructional programs designed expressly for school curricula.[4] The last category includes a range of materials, from simple drill and practice routines and other electronic equivalents of the conventional workbook, to sophisticated simulation, problem solving, and tutorial software that makes use of artificial intelligence and multimedia technologies, to full curricula that theoretically can substitute for teachers.[5]

While the question whether to install computers in schools is by now moot, neither the future development and acquisition of appropriate software nor the effective use of these learning tools is as certain as in other sectors of society. The economic and social environment of American public schools is fundamentally different from the worlds of business, the military, medicine, the arts, and science. Finding affordable software for schools and finding out how best to use it are challenges that must be met if technology is to achieve its desired effects.

[1]This chapter is based in part on two OTA contractor reports: W. Curtiss Priest, "Educational Technology: Information Networks, Markets and Innovation," September 1987; and Ellen Bialo and Jay Sivin, "An Analysis of the Scope and Quality of the Current Supply of Educational Software and of the Available Sources of Information on Educational Software," Sept. 30, 1987.

[2]A good example comes from the *Observer*, which noted that an arms agreement had been phrased "in terms of giving the United States 'software'—a more flexible attitude on the Middle East—in return for 'hardware' -arms and military equipment. " Cited in *Supplement to the Oxford English Language Dictionary*, vol. 4 (Oxford, England: Oxford University Press, 1966), p. 333.

[3]*Scientific American* devoted an entire issue to computer software and its role in business, science, and medicine, but did not address education per se. See *Scientific American, vol. 251,* No. 3, September 1984, and especially the article by Alan Kay, pp. 52-59.

[4]The administrative software that many schools acquire to automate scheduling, personnel, and student records clearly plays an Important role in creating an interactive educational atmosphere, but is beyond the scope of this report.

[5]OTA has found no evidence of teacher displacement by computers and related technologies. However, shortages of teachers in some fields and in some parts of the country has spurred interest in the development of comprehensive, interactive curricula. See Arthur Melmed and Robert Burnham (eds.), *New Information Technology Directions for American Education: improving Science and Mathematics Education* (Washington, DC: National Science Foundation, December 1987). A resurgence in education school enrollments, following two decades of sharp decline, may partially offset the predicted teacher shortages. But there are still grounds for concern that future requirements will not be met. See Joseph Berger, "Allure of Teaching Reviving; Education Schools Rolls Surge," *The New York Times,* May 6,1988, p. 1.

This chapter takes a close look at educational software's problems and promise, and suggests how the Federal Government might help to remedy the former and realize the latter. In addition, while educational computer software is an important subject in itself, this analysis has wider relevance: the challenges educaters face in using computer software in schools are similar to some they already face, or soon will, using many other forms of interactive technology.

FINDINGS

Quantity, Quality, and Scope

- There are now over 10,000 available stand-alone (floppy disc-based) instructional programs produced by about 900 firms. In addition, about a dozen major manufacturers specialize in producing expensive and elaborate "integrated learning systems" (ILSs) that span large segments of the elementary and secondary curriculum.
- The technical quality of most commercially produced software is quite good. However, there is a general consensus that most software does not yet sufficiently exploit the capacity of the computer to enhance teaching and learning.
- It will be difficult to justify the costs of acquiring and implementing new interactive learning tools unless their software genuinely improves upon conventional learning materials. However, innovative software that departs from familiar teaching methods, and that may be highly respected by computer scientists and educational technologists, is not necessarily selected by teachers. Pressured to raise test scores and meet other performance mandates, many teachers prefer software that is closely tied to the curriculum; and software publishers can usually strengthen their market position by developing products that are linked to textbooks and other familiar instructional materials.
- While commercial software publishers are reluctant to take risks with innovative software, many of the available titles are attractive and fun to use, even if they are geared toward familiar objectives. Even the most rudimentary drill and practice programs have been proven effective in raising some children's basic quantitative and language skills.
- Many teachers use database, spreadsheet, and word processing programs that are not necessarily new in concept or design. These programs have become powerful new classroom tools and are applied in exciting ways to traditional classroom activities.
- Mathematics programs continue to dominate the market. Although there have been some increases in the availability of software for social studies and language arts, at the same time there has been a slight decrease in the number of new science programs, especially chemistry and physics.
- In the category of didactic programs, the vast majority of titles aim at basic skills. Software to teach "higher order" skills, such as hypothesis testing and problem solving, is in much shorter supply. Drill and practice software continues to dominate all subject areas, to the chagrin of many educators and educational technologists.

Market Characteristics

- Most of the firms that manufacture stand-alone educational software are small—the average firm has two employees. Even the largest firms have an average of only 35 employees. Total annual sales in this market were approximately $170 million in 1987.
- Integrated software that covers entire curricula are very expensive to develop. Firms in the ILS market, as distinguished from the stand-alone market had annual sales of roughly $100 million in 1987. These firms have found that their ability to raise venture capital is governed by two main factors: evidence that their learning systems can achieve positive results on standardized tests, and evidence that their systems are cost-effective (that they can achieve defined objectives more efficiently than other methods).
- The demand side of the software market consists of thousands of independent school districts with varying administrative rules, serving a diverse pop-

ulation of school children with differing needs, talents, and learning styles.

- The number of children in a given grade, learning a particular subject, represents a small fraction of the total student population. An even smaller proportion have regular access to computers, a fact that poses a formidable problem to software developers and vendors. Teachers, computer coordinators, and instructional design experts are concerned that in trying to serve such a fragmented market software publishers will be inclined toward increasingly homogeneous and less innovative products.
- While the cost of developing software (especially the type marketed on floppy discs) has dropped considerably due to advances in programming environments and the know-how of programmers, marketing to the educational sector remains a costly, sometimes prohibitive factor.
- The existence of numerous information channels makes it difficult for software producers to receive clear market signals and to adjust their designs accordingly. State and local initiatives to define curriculum needs and invite targeted software development have met with mixed results.
- A limited survey of software publishers indicates that the larger concerns are typically both more rigid (bureaucratic) and less innovative than smaller firms. Evidence of the performance of firms of different sizes and market share is mixed and inconclusive.
- The problem of unauthorized copying (piracy) continues to undermine investments in new product development, especially among smaller publishers with little experience in the school market.
- The principal factors that will determine the structure and quality of the educational software industry are: high development costs for innovative state-of-the-art applications; marketing advantages that accrue to incumbents in the school market; risks associated with idiosyncratic acquisition policies and procedures; small demand for subject and grade specific products; and the difficulty of appropriating the returns to investments in software that is easily copied.

QUANTITY AND SCOPE OF THE EDUCATIONAL SOFTWARE SUPPLY

When computers were first used for instruction in the late-1950s, software consisted largely of drill and practice materials delivered from mainframe computers to students working at “dumb” terminals. Students could not modify the programs. Since then, educational software has come to include everything from computer programming languages to networked simulation programs that allow instantaneous international communication of data.

The companies that manufacture different kinds of products face different problems and compete in specific markets. The three principal sources of software are suppliers of free-standing floppy disc-based programs, manufacturers of ILSs that sometimes come bundled with dedicated hardware, and developers of public domain and “shareware” products that are accessible through electronic bulletin boards, interest groups, and various cooperative organizations. The last group of products are typically produced by teachers, students, and computer buffs to fill specific curriculum niches that commercial developers have neglected. It is difficult to estimate the size of the informal shareware market for elementary and secondary school, although a growing number of teachers use shareware via electronic bulletin boards. In addition, there is considerable trickling down to the upper secondary grades of software created for postsecondary environments, much of which is distributed by nonprofit organizations or by joint commercial arrangements. [h]

Integrated Learning Systems: The High End of the Software Market

ILSs are packaged to span part or all of a curriculum (for example, fourth to sixth grade arithmetic

[h] One example in higher education is the Apple University Consortium, which promotes academic software exchange through Kinkos, a nationwide chain of photocopying centers.

or K-6 language arts), and typically run on networked systems of microcomputers linked to a file-serving micro or minicomputer. Many ILSs are designed to run on hardware that is already in the schools, such as Apple or MS-DOS compatible machines, and some ILS manufacturers have become licensed vendors for one or more computer companies. Some schools prefer to purchase hardware directly from manufacturers, because of price advantages; others prefer one-stop shopping and purchase bundled systems from the ILS software developers. These systems are usually packaged with curriculum guides and management tools, and are typically geared toward basic skills improvement. They all claim to ". . . offer the advantages of using computers to diagnose, reinforce, and enhance learning individually, to monitor student improvement, and to produce documented evidence of gains. Most companies correlate [software] to district goals, curriculum, and standardized tests."[7]

The appeal of these systems is their comprehensive coverage: in terms of lesson planning and integration of electronic media, they make fewer demands on teachers than do individual programs that treat small sections of the curriculum. ILS developers are aware that the centralized approach may be perceived as mechanistic and inflexible, so they go to great lengths to show that their materials can be tailored to individual students' needs and abilities.[8] An additional important selling point is the system's ability to accommodate other companies' software: school personnel who want the option of using programs developed by other companies, now or in the future, often choose integrated systems that run on standard microcomputers.

Some systems permit students to advance at their own pace through a fixed curriculum; others permit students to move horizontally within subjects, for example, to move from a study of the planet Earth to the larger solar system, depending on prior knowledge and rate of learning. Nevertheless, all these systems permit considerably less flexibility than generic tools such as word processors and individual instructional programs that teachers can apply to specific segments of the curriculum.

Another important factor is cost. A typical algebra course, providing 100 contact hours for the middle school grades, can cost upwards of $1 million to develop. The costs of installing an ILS, including hardware, software leasing, maintenance, and training, can run as high as $100,000 for a laboratory with 20 or 25 terminals. For a school district this translates to multimillion dollar contracts, and therefore necessitates a long-term commitment to both the network concept and the particular software.[9]

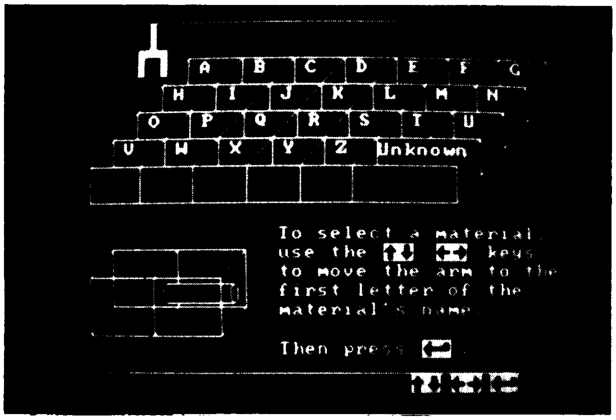
The companies that manufacture these systems include Education Systems Corp., Wasatch Education Systems, Prescription Learning Corp., Wicat, Degem Systems, Houghton Mifflin, and Unisys. Their products have been heavily influenced by the early experiences of the Computer Curriculum Corp. (CCC) and of Control Data Corp. (CDC). CCC, under the leadership of Patrick Suppes, a noted philosopher and decision scientist, was one of the first developers of computer-assisted instruction systems, and has retained a significant market share. CDC's PLATO system, once a pioneer in computer-based training, has strived to maintain its place in the education market with updated tutorials and drill materials.

While some firms entered this market with substantial capital resources (CDC, for example, was already a manufacturer of mainframe computers), the majority have relied on venture capital. Their ability to raise venture capital has been governed primarily by two factors: evidence that their learning systems can achieve tangible results, usually improved performance on basic skills tests; and evidence that their learning systems are cost-effective (that schools will choose to purchase those systems rather than rely on other strategies to achieve the same objectives). Even the smallest firms in this industry have had to raise substantial sums (at least $5 million), and have devised creative public/private consortia. In one case, private venture capital of about $1.2 million was leveraged to gain commitments from a consortium of school districts

[7] Gwen Solomon, "In An ILS, LANS are Part of a Larger Teaching System," *Electronic Learning, vol. 7, No. 4,* January 1988, p. 27.

[8] Integrated learning systems programs are not necessarily limited to drill and practice: ". . . one is as likely to find problem solving, simulations, and tool software in integrated learning systems as one is to find such programs among the general mix of floppy disk programs. . . ." Ariela Lehrer, "A Network Primer: How They're Used . . . and How They Could be Used," *Classroom Computer Learning,* vol. 8, No. 7, April 1988, p. 42.

[9] See also ch. 4 for a detailed illustration of the costs of acquiring and implementing an integrated learning system.



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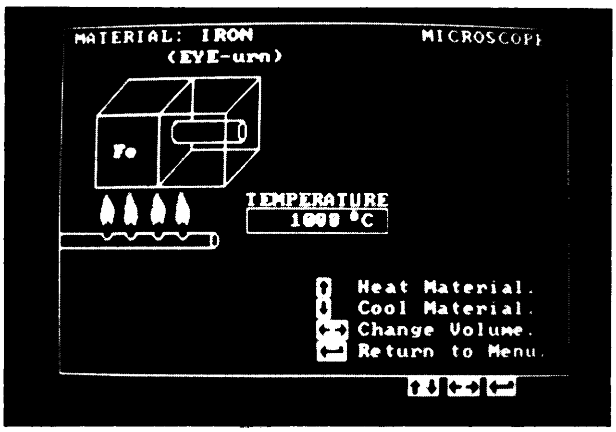

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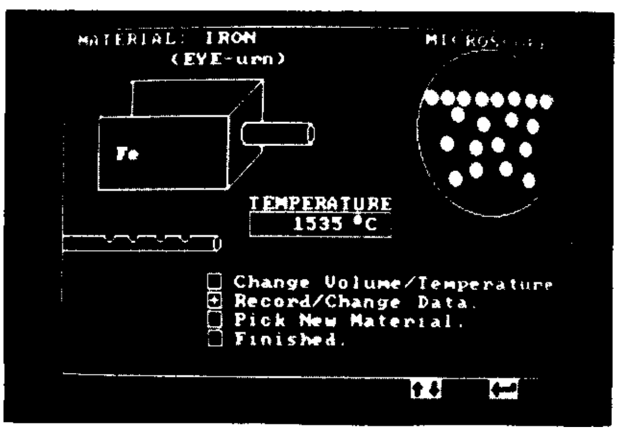

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whose joint participation brought the total funding base to about $5 million. A larger firm, which was able to raise over $20 million in the same amount of time, has moved more rapidly in the development and production of more comprehensive systems.

The grade span of the courseware, as well as its scope, reflects to some extent the size and capitalization of the company. Prescription Learning Corp., for example, with estimated annual sales of $40 million and with installed laboratories in most of the 50 States, offers a complete kindergarten-adult curriculum in basic skills, writing, English as a second language, adult education, GED preparation, and vocational education. [10] Smaller and newer entrants in this market have necessarily focused their efforts on smaller segments of the curriculum, such as fourth to sixth grade reading or junior high school mathematics.

The Low-Priced Market: Stand-Alone Software

The alternative to networked and integrated learning systems is the use of floppy disc-based programs that typically cost under $50 and address specific topics or concepts rather than an entire curriculum.[11] There are now over 10,000 such software titles available, covering the major school subjects and many of the minor subjects, produced by an estimated 900 firms. In the general software market, 85 percent of sales are accounted for by less that 20 percent of firms; in educational software, the top 25 firms account for about 65 percent of sales, with average sales of $4 million. The average firm in this segment of the educational software industry has less than 2 full-time employees, and even the top 25 firms are relatively small, averaging about 35 employees.

The amount of money spent by schools on educational software, about $170 million in 1987 according to the Software Publishers Association, represents a tiny fraction of total 1986-87 expenditures

[10]Solomon, op. cit., footnote i'.

[11]Most Integrated learning systems run on computers that can accommodate individual floppy disc-based programs as well; but the typical free-standing microcomputer found in American schools, e.g., the Apple II-c, does not have sufficient memory capacity to handle integrated software s}, stems.

on elementary and secondary schools: it is approximately 0.1 percent, or about $1 in $800. Assuming roughly 40 million public school students, the average outlay for software in 1987 was about $4.25 per student, out of a total of about $35 per student on all instructional materials (including books).

Firm Size and Innovation

Firms in this market vary significantly by size and organizational structure, and employ different production and sales strategies. In addition, interviews conducted with 10 educational software companies revealed a range of attitudes about important issues facing this industry .[12] From discussions with the chief executive officers, marketing vice presidents, or product development managers at the firms chosen for this survey, OTA found that the largest firms are typically the most bureaucratic, as might be expected. These firms also appear to be less innovative than smaller ones, an impression which is consistent with findings on a wide range of industries in the United States and abroad.[13] The three largest firms in the sample, with annual sales in the range of $25 million to $3.6 billion, were found to be relatively noninnovative. In fact, small firms believed that scale advantages of their larger competitors did not result in better products or greater market power.

However, some of the most important new software ideas have been successfully commercialized by large firms, which means that size alone is a poor predictor of innovative capacity. Firms use different methods to generate new ideas and update their product lines. In some, current or former educators are on the full-time staff; in others, teachers are paid royalties from sales of software they have designed or written. Another approach is to rely on information from dealers, from the sales force, and from direct contact with teachers. In addition, professional journals, national computer exhibits and conferences, and regional conventions are cited as important sources of innovative ideas. Hardware suppliers were never mentioned as sources for software innovations. It is difficult to assess the research and development efforts of firms in this industry, especially because the smaller ones tend not to distinguish expenditures on these activities from other business expenses.

Small firms in this sample did not perceive a greater threat from unauthorized copying than the larger firms. Advances in copy protection and dedication to providing new learning tools for children were the reasons mentioned for not being overly concerned with unauthorized duplication. It should be noted, however, that copying continues to preoccupy industry associations as well as many publishers, who have issued strident calls for increased copyright protection. At least one small educational software publisher has called for a governmental ban on the sale of disc-copying technology;[14] and controversial copyright infringement lawsuits continue to occupy headlines in the computing and general press.[15]

The Analogy to Textbooks

Many of the largest firms that supply educational software are textbook publishers that have entered the software business hoping to capitalize on their expertise in marketing to schools. As a result, they are inclined toward strategies that work well in the book business but that may inhibit software innovation. By linking computer products to textbooks—both their own and competitors'—these companies are further solidifying the curricula that some educators are attempting to reform. Textbook companies argue that products with recognizable curricular goals will be attractive to teachers, who will therefore be more willing to promote expanded use and innovative applications of the technologies in the classroom. But textbook publishers have not always been successful in the software market. Sales representatives who usually work on a commission basis can make more money by concentrating on book orders, which are much larger than software orders. (This is what is meant by fragmented demand for software, and is a function of the relatively small amount of time most students spend with com-

[12] For methodological detail about these Interviews, see Priest, op. cit., footnote 1.

[13] Morton Kamien and Nancy Schwartz, *Market Structure and Innovation* (Cambridge, England: Cambridge University Press, 1982).

[14] Dwight Johnson, The Home School, San Diego, CA, in U.S. Congress, Office of Technology Assessment, "Transcript of Proceedings—OTA Workshop on the Educational Software Market," unpublished typescript, Aug. 6, 1987.

[15] See Richard M. Lucash, "Look and Feel Lawsuits, " *High Technology Business*, October 1987, p. 17; and Katherine M. Hafner and Richard Brandt, "Does This Lawsuit Compute for Apple?" *Business Week*, Apr. 4, 1988, p. 32.

puters.) As a result, some companies have tried to separate their book and software divisions, but in so doing have sacrificed economies of scope (see box 6-A).

Some of the most successful software publishers are not in the book business, but are subject to the same types of political and market forces that have shaped the textbook industry (see boxes 6-B and 6-C). Growing concern with the quality and diversity of that industry's products, coupled with wide agreement that innovation is crucial for interactive technologies to achieve their desired effects in education, has spurred interest in the analogy between the textbook and computer software markets.

The principal criticism of American textbooks is leveled not against book publishers, but rather against the system and environment in which they operate: "The source of the writing problem is not in the publishing house, but in the public agency. Legislators, educational policy makers, and administrative regulators have unintentionally drained the life out of children's textbooks.'" This criticism is consistent with other analyses conducted over the past decade. In 1978, the textbook market was described thus:

> A planner setting out to design a system guaranteed to discourage the purchase of innovative instructional materials would be hard-pressed to improve on the system for materials selection that is followed throughout the country today. Although margins for efficacy and diversity do exist, the overwhelming preference is for the lowest, least unsettling common denominator in instructional materials content. This pattern of preference stems from a concert of forces. Instructional materials selection is an open textured process, inviting and accommodating the opinions and decisions of State lawmakers, State and local school administrators, teachers, parents and students, and the variety of organizations into which they group themselves. The fact that current patterns of consumer prefer-

"Harriet Tyson-Bernstein, *A Conspiracy of Good Intentions: America's Textbook Fiasco* (Washington, DC: Council for Basic Education, 1988).

Box 6-A.-"Early Burned, Inc."

A prominent firm in school textbooks, Early Burned made two critical errors: it separated its software division entirely from the book division, and it produced a line of products that were intended for a computer that would subsequently be withdrawn from the market. Just 3 years after starting, the software division was completely shut down. Since then the firm has cut back its software line from over 100 titles to about 25. Lack of backing from the book division, coupled with software designed for use with a computer that was one of the first casualties in the hardware shakeout of the early 1980s, led to the failure of the software division. The remaining 25 software titles produced by this firm account for less than 0.5 percent of total sales. The firm has become extremely cautious with its innovations and product line. Company executives and market strategists have adopted a policy to keep software closely tied to textbooks, both organizationally and with respect to content.

Early Burned views the education market for software as "., , . one where the buyers keep demanding higher quality but are willing to pay less and less." The market is becoming more and more competitive and will probably never be as profitable as textbooks: barriers to entry and high margins make it a "hot" industry.

The central strategy of this firm is to link software to books. In the words of the Vice President for Marketing,". . . schools had better be using our texts. , . "to match with the software. This linkage gives the company an obvious market advantage, especially because teachers know and respect the books and are, therefore, willing to experiment with the computer applications. The implication of this strategy is that high-risk projects are simply not undertaken. The typical investment is about 1 person-year, and extravagant projects that have been launched by some competitors would not be approved. In fact, the firm is a bit frightened by new technologies, such as compact disc-read only memory (CD-ROM), and is not planning to invest in the necessary programming talent.

SOURCES: OTA interviews with software publishers; and W. Curtiss Priest, "Educational Technology: Information Networks, Markets and Innovation," OTA contractor report, September 1987. The name of the company has been changed to preserve confidentiality.

Box 6-B.—"Major Force, Inc."

Major Force is one of the larger companies that develops software but does not sell textbooks. It is an innovative company, with considerable brand recognition in the industry, employing over 200 people and producing over 100 software products. The company was founded about 15 years ago, is privately held, and began by developing filmstrips for health and guidance. Many former teachers work at Major Force, in a computer division established 5 years ago.

The company works in three main product areas: elementary print materials, filmstrips, and computer software. There is little or no integration between software development and the other activities. Marketing is through direct mail catalogs, in addition to 1 sales person who concentrates on the top 20 school districts. Major Force no longer works with the independent dealer network, preferring to focus their efforts on direct telephone support for customers. According to the Vice President for Marketing, the company judges the market by "intuition," "facts," and conversations with people. They do not believe in surveys because there is too much uncertainty in the minds of respondents.

The leadership style at Major Force is "participatory." As the software business grew, there was a concern for preventing the bureaucracy from encroaching on the software developers' creativity. Five development offices around the country are kept small, with 1 key person, 3 programmers, and up to 10 part-time staff.

This firm considers the education market "good, but difficult." Brand recognition brings stability, and the market as a whole is considered more secure than the home software market. Software is not directly oriented to curricula, except when curriculum changes are amenable to software solutions. For example, the trend to view "writing as a process" brings opportunities for good software development.

Curiously, Major Force is not terribly concerned about piracy at the school level. Their products are copy protected, mainly to prevent dealers from making illegal copies. School boards are viewed as doing a good job of preventing piracy.

Finally, Major Force does not believe there are significant economies of scale in this business. But they are quick to point out that small and innovative firms succeed only if they are quick and if they know their market. Thus, the transaction costs of an uncertain and complex market are important barriers to entry, while ". . . knowing the ins and outs of the business creates opportunities and lowers competition."

SOURCES: OTA interviews with software publishers; and W. Curtiss Priest, "Educational Technology: Information Networks, Markets and Innovation," OTA contractor report, September 1987. The name of the company has been changed to preserve confidentiality.

ence are formed from so many forces helps to explain their persistence and the futility of efforts to alter the pattern by altering one or even a handful of the elements that form it.[17]

Developers and publishers of instructional software face-similar problems in their attempt to satisfy the demands of educational consumers. At present, however, there appears to be far less political intervention in software acquisition than in textbook adoption. Teachers, parents, children, and administrators all have some say, but the selection process is typically much less formal and less bureaucratic than for books. There is some concern that as interactive media become more prominent in classrooms, software decisions may become entangled in the political forces that have influenced book content and quality.

The analogy between books and software *is* not limited to bureaucratic features. Market forces, even in the absence of divergent political interests, play a role. First, good ideas for textbook revisions quickly become "public goods," and their authors cannot be sure to recoup development costs.[18] In

[17]Paul Goldstein, *Changing the American Schoolbook: Law, Politics and Technology* (Lexington, MA: Lexington Books, 1978), p. 53. For a rejoinder see Alexander J. Burke, "Textbook Publishing in America," *The Textbook in American Society, J.* Cole and T. Sticht (eds.) (Washington, DC: Library of Congress, 1981), p. 47. See also Harriet Tyson-Bernstein, "The New Politics of Textbook Adoption," *Phi Delta Kappan*, March 1985; and Frances Fitzgerald, *America Revised* (Boston: Little Brown, 1979).

[18]The relationship between intellectual property protection and returns to innovators, in general but not with specific reference to educational technologies, is the subject in David Teece, "Profiting From Technological Innovation: Implications for Integration, Collaboration, Licensing, and Public Policy," *Research Policy, vol. 15, 1986,* pp. *285-305. See* also Goldstein, op. cit., footnote 17, for a discussion of copyright and other property rights protections as they impinge on instructional materials development.

Box 6-C.--"Street Vendor Co., kc."

For a firm with only one and one-half employees, the annual sales volume of $250,000 and the number of software packages produced-80-is surprisingly high. The President of the firm has considerable prior experience with large companies, but wanted a greater "sense of service," and, therefore, created this company in 1980.

Many of the programs marketed by Street Vendor are written by teachers. They cover a wide variety of topics, from alphabet skills to geographical statistics to college-level tutorials. Outside authors are attracted to Street Vendor by the possibility of earning royalties (15 percent of sales, net of discounts and freight charges), and respond quickly without the imposition of rigid deadlines.

Products are not matched to school curricula, but teachers and students seem receptive nonetheless. To avoid the catastrophic consequences of a "big mistake," projects are kept small and manageable; the ones that do not seem to work are dropped quickly. Piracy is a problem that this firm cannot solve; besides copy protecting some preview discs, they essentially ignore the unauthorized copying problem. A central concern is that teachers who see many similar programs will increasingly prefer familiar brand names. Finally, Street Vendor resents having to compete with companies that started out under State auspices and who, therefore, enjoy significant (and unfair) competitive advantages.

Street Vendor perceives the market as reasonably strong, but weaker than some years ago. If the President were interested in more profit, rather than in the entrepreneurship of owning and managing his own firm, he says he would go into the business market.

SOURCES: OTA interviews with software publishers; and W. Curtiss Mat, "Educational Technology: Information Networks, Markets and Innovation," OTA contractor report, September 1987. The name of the company has been changed to preserve confidentiality.

addition, there is a strong economic rationale for producing books and software that are familiar to consumers, rather than attempting to gain market share by introducing a truly differentiated product. Together these factors create a disincentive to innovate.

As instructive as these comparisons may be, there are important differences between books and software that should also be taken into account. First, as suggested above, the reason so many people are involved in decisions about books is because of their *content*. Most instructional software, on the other hand, even the didactic kind, focuses on learning *processes*, about which there may be less ideological controversy. Even programs that are closely linked to existing textbooks do not simply translate the material found in those books into electronic screen images but rather provide supplementary drill and exercises. Second, some of the most popular software programs in the schools are generic word processors, database management systems, and spreadsheets. These programs are completely neutral in content, and are not likely to arouse conflict between parents, school boards, teachers, and legislators. The strength of the analogy between textbooks and software, therefore, depends in part on the balance between generic and content-specific (and value-laden) materials adopted by teachers and schools, and in part on the perceived impact of the technology upon local curriculum planning.[19]

Scope of Instructional Software

OTA analyzed several comprehensive educational software databases to characterize the quantity and coverage of educational software products.[20] As shown in table 6-1, mathematics, science, English, reading, and social studies account for the greatest share of these products. Publishers of educational software are influenced by their perception of the subject areas that comprise most of the instructional

[19] Local curriculum planning and school management, and the degree of teacher autonomy in the classroom, are critical issues in American education policy, with implications for educational software. Some reformers advocate greater teacher (and parent) participation in school decisionmaking, along with other initiatives to enhance the professional status of teaching. Generic software that provides teachers with increased opportunities is compatible with this general strategy of reform. However, others question whether a sufficient proportion of teachers currently are able and willing to work effectively with open-ended materials. It is clear that the relationship between expanded individual choice and quality control should be a central criterion in the design of appropriate software.

[20] Bialo and Sivin, op. cit., footnote 1.

Table 6-1.-Distribution of Educational Software Programs by Subject (N=7,325)

	Percent of programs[a]	Number of programs[a]
Comprehensive	6	427
Computers	5	331
English/language arts	12	894
Foreign language	5	356
Mathematics	27	1,971
Reading	12	869
Science	16	1,148
Social science	8	565
Other[b]	18	1,329

[a]The sum of the programs is greater than N because some programs We assigned to more than one subject category. Accordingly, the total of the percentages is greater than 100 percent. All percentages were rounded tothe nearest unit.
[b]The Other category combines 13 subjects (agriculture, aviation, business, driver educat ion, early learning/preschool, fine arts, guidance, health, home economics, industrial arts, library skills, logic/problem solving, and physical education, each of which accounts for less than 4 percent of the total number of programs.

SOURCE: Office of Technology Assessment, based on analysis of data in the Educational Products Information Exchange, July 1987.

day, as well as by their perception of teachers' preferences.

For example, within the general category of reading, there are more programs in vocabulary and comprehension than in decoding skills (see table 6-2); and in mathematics the majority of software titles aim at basic skills (see table 6-3). A strong indicator of suppliers' attempts to satisfy school demand is the variation by grade range. As shown in table 6-4, most of the kindergarten software is intended for reading, mathematics, and preschool skills taught at this level. In the higher grades, the distribution shifts, with less emphasis on reading and graduall y increasing emphasis on science programs. In general, the higher grades are served by a greater variety of subjects, including foreign language and business.

Table 6-2.—Distribution of Reading Software by Area (N =869)

	Percent of programs[a]	Number of programs[a]
Comprehension skills	24	210
Decoding skills	10	87
Reading in content areas	6	54
Reading readiness	20	174
Vocabulary	38	333

[a]The sum of the programs is less than N because some programs would not fit any of the area categories. Accordingly, the total of the percentages is less than 1000/o. All percentages were rounded to the nearest unit.

SOURCE: Office of Technology Assessment, based on analysis of data in the Educational Products Information Exchange, July 1987

Table 6-3.—Distribut[on of Mathematics Software by Area (N =1971)

	Percent of programs[a]	Number of programs[a]
Basic skills	72	1,425
Algebra	10	201
Geometry	6	123
Other[b]	11	225

[a]The sum of the programs is greater than N because some programs were assigned to more than one area category. The total of the percentages Is still equal to 100 percent, since all percentages were rounded to the nearest unit.
[b]The Other category combines 10 areas (analysis, calculus, consumer mathematics, differential equations, finite mathematics, general mathematics, number theory, probability statistics, and trigonometry), each of which accounts for less than 4 percent of the total number of programs.

SOURCE: Office of Technology Assessment, based on analysis of data in the Educational Products Information Exchange, July 1987.

Table 6-5 gives an estimate of the "fit" between software availability and amount of time in the school day allocated to the corresponding subjects. For the junior and senior high school grades, the fit is strongest for mathematics and communications (which includes English/language arts and reading), with some apparent discrepancies for social and natural sciences and the fine arts.

The discrepancies (which seem to be more pronounced at the junior high level) point to another factor influencing the quantity and scope of software. Developers are influenced not only by their understanding of curriculum scope and sequencing, but also by their ability to apply state-of-the-art programming and design techniques to different instructional areas. It is clear, for example, that the earliest applications of computers—in all fields—were in *computing:* performing arithmetic operations that would otherwise have taken countless human hours to complete. With this head start, it is not surprising that much of the early educational software enabled teachers and students to work on basic computational skills (such as adding and subtracting) through a variety of electronic versions of workbooks, flash cards, and other routinized functions. Mathematics programs continue to dominate the market, although there have been some slight increases in the availability of software titles for social studies and language arts. In fact, one of the most popular programs (Where *in the World is Carmen Sandiego?* published by Broderbund), is used to teach geography, a subject which has also attracted the attention of developers working in interactive video.

Table 6-4.—Distribution of Educational Software by Subject Area and Grade Range (N =7,325) [a]

Subject	Grade range K	1-3	4-6	7-8	9-12
Business	00/0	1 %	2 %	3 %	4 %
	1	16	61	106	205
Comprehensive skills	7%	4%	5 %	6 %	70/0
	41	86	167	224	363
Computers	4%	3 %	4 %	5 %	6%
	27	61	131	209	294
Early learning/preschool	240/o	7 %	0 %	O%	00/0
	146	139	11	2	o
English/language arts	7%	19%	18%	14%	9 %
	45	373	646	532	462
Fine arts	5%	4 %	40/0	4 %	30/0
	32	81	143	144	145
Foreign language	1%	1 %	4%	7 %	70/0
	4	29	134	264	343
Home economics	00/0	O%	2%	3 %	4%
	o	5	57	125	176
Logic/problem solving	1 %	3%	30/0	3 %	20/0
	8	58	122	115	97
Mathematics	19%	21%	22%	21%	160/0
	115	402	775	807	767
Reading	31%	26%	160/0	90/o	60/o
	192	511	545	334	279
Science	10/0	40/0	8%	120/0	21%
	4	70	275	451	1,031
Social science	1%	40/0	90/0	10%	8%
	5	75	313	398	404
Other	1%	20/0	30/0	5%	7'%
	1	40	116	208	357
Total programs	621	1,946	3,496	3,919	4,923

aPercentages (rounded to the nearest whole number) refer to column totals. Forexample, of a total of 621 programs intended for use *in* kindergarten, 31 percent were in reading. Below each percentage is the number of programs in a given subject intended for that grade range Total programs are greater than 7,325, because programs can be classified in more than one grade range

b"Other" combines agriculture, aviation, driver education, guidance, health, industrial arts, library skills, and physical education, each of which accounts for less than 4 percent of the total programs in each grade range.

SOURCE Office of Technology Assessment, based on analysis of data in the Educational Products Information Exchange, July 1987

Table 6-5.—Curriculum Requirements and Available Software: Middle and High Schools

	Middle schools: Time spent[a]	Middle schools: Availability of software[b]	High schools: Time spent	High schools: Availability of software
Communication skills	High	High	High	High
Social science	High	Moderate	High	Moderate
Mathematics	High	High	High	High
Science	High	Moderate	Moderate	Moderate
Fine arts	Moderate	Low	c	c

aThe proportion of time spent on an given subject ranges from less than 1 percent to 18 percent in grades 7 and 8, and from 1 Percent to 23 Percent in grades 9-12 Subjects accounting for 13-18 percent are rated "High," subjects accounting for 7-12 percent are rated "Moderate. "

bTh proportion of available software for any given subject ranges from less than 1 percent to 23 percent fOr the middle grades, and frOm leSS than 1 PerCent to 24 percent for the high school grades "High," "Moderate," and Low," respectively, refer to subjects that account for 17 to 24 percent, 9 to 16 percent, and less than 9 percent of available titles for the middle grades; and to subjects that account for 16 to 23 percent, 8 to 15 percent, and below 15 percent, for the high school grades

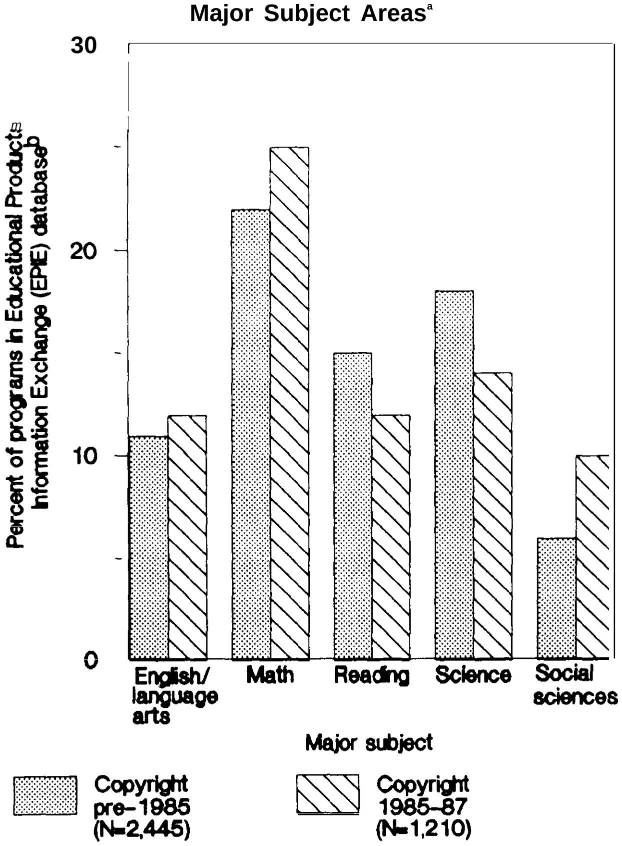
f+. Jot included in grades 9-12

SOURCES For time spent, data from Departments of Education in eight States; for availability of software, Educational Products Information Exchange, July 1987 For methodology of class! fication used in this table see Ellen Bialo and Jayu Sivin, "An Analysis of the Scope and Quality of the Current Supply of Educational SOftWare and of the Available Sources of Information on Educational software," OTA contractor report, Sept 30, 1987.

At the same time, the number of new science programs, especially in chemistry and physics, has decreased (see figure 6-1), to the disappointment of many educational technologists who are concerned about the state of science teaching in the United States. The reason for this decline is difficult to establish. However, one explanation may be that many of the early science programs were quickly found to be wanting, especially in comparison with the new "microcomputer-based laboratories, " and were discontinued. At the same time, high development costs have prevented all but a few players from entering this field. The net result is fewer, but generally more sophisticated, programs.

The importance of perceived teacher demand and technical-ability in shaping the scope and quantity of software is demonstrated by statistics on the type of software available on the market. As shown in table 6-6, the vast majority of titles provide drill, skills practice, and tutorials. Software to develop so-called "higher order thinking skills," such as hypothesis testing and concept development, is in thin supply. In addition, as shown in table 6-7, drill, practice, and tutorial software continues to dominate all subject areas, to the chagrin of many educators and educational technologists. The fact that teachers have often preferred this type of software, which is typically closely linked to curriculum sequences and/or to texts or other instructional materials, suggests that the market responds well to demand signals, but also points to a fundamental predicament: products that are highly rated by "experts" because they represent the most innovative uses are not necessarily the ones preferred by most teachers.[21]

Figure 6-1.—Trends in Availability of Software for Major Subject Areas[a]



[a]Does not include programs in subjects such as problem solving, fine arts, foreign language, or business.
[b]Includes only those programs in the database, that specify a copyright date (3,655 programs). No copyright information is available for approximately half of the programs in the database.

SOURCE: Office of Technology Assessment, based on contractor's analysis of data in the Educational Products Information Exchange, July 1987.

School Uses of Noninstructional Software

Many software products purchased for school use were originally developed for other applications. The home market, for example, has influenced the types of software acquired by schools.[22] Some educators

[21]This issue was discussed at length by participants at the "OTA Workshop on the Educational Software Market," op. cit., footnote 14.
[22]Use of "home" products in schools, and vice versa, makes it difficult to calculate educational software sales and other market statistics with precision.

Table 6-6.—Distribution of Educational Software by Type (N =7,325)

	Percent of programs[a]	Number of programs[a]
Rote drill	15	1,107
Skills practice	51	3,708
Tutorial	33	2,447
Concept demonstration	3	216
Concept development	4	270
Hypothesis testing	1	91
Educational games	19	1,425
Simulations	9	669
Tool programs	11	807

[a]The sum of the programs is greater than N because some programs were assigned to more than one category. Accordingly, the total of the percentages is greater than 100 percent. All percentages were rounded to the nearest unit.

SOURCE: Office of Technology Assessment, based on analysis of data in the Educational Products Information Exchange, July 1987.

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Table 6-7.—Distribution of Major Subject Software by Type

	Program type									
Subject	Rote drill	Skills practice	Tutor	Concept demonstration	Concept development	Hypothesis testing	Educational games	Simulations	Tools	Subject total
English/language arts	26°/0	72%	360/o	0%	1%	0%	240/o	0%	60/0	
	229	640	318	1	13	1	216	2	58	894
Mathematics	90/o	550/0	280/.	2%	3%	O%	13%	3%	50/0	
	186	1,089	550	49	61	0	264	52	94	1,971
Reading	250/0	740/0	240/0	0%	1%	0%	290/0	0%	20/0	
	215	645	207	0	12	0	253	4	16	869
Science	9%	370/o	450/o	80/0	60/0	1%	12 "/0	32%	8%	
	107	424	514	88	70	12	140	365	89	1,148
Social science	180/0	320/o	37 "/0	4%	7%	2%	320/o	21%	4%	
	100	182	209	25	37	13	183	119	24	565

NOTE: Each row gives percentages (rounded) of all programs in a subject area that are of a given type. For example, 55 percent of all mathematics programs were in the "skills practice" category. Below each percentage is the number of programs in a subject and category. Rows sum to more than 100 percent of the total for each subject because programs can be classified in more than one type.

SOURCE: Office of Technology Assessment, based on analysis of data in the Educational Products Information Exchange, July 1987.

are skeptical about games, while others recognize their potential educational value. Similarly, software originally developed for the business environment has also become enormously popular among teachers, children, and parents alike. Word processing programs, for example, have become a staple of writing classes; some have been customized to allow for illustrated story composition and other activities appropriate to primary and secondary grades. A best-selling software product on the educational market today is an integrated word processing, database management, and spreadsheet utility. The success of this program suggests that many teachers prefer generic materials that improve the way children approach many different subjects over didactic programs that provide specific lessons. This type of software also appeals to parents who want their children to be prepared for a world of work that depends on similar interactive technologies.

Photo credit: Scholastic Software

Teachers use word processing software such as the *Bank Street Writer* to help students improve their writing skills, teaching them to analyze and revise drafts until they have expressed themselves as clearly as possible.

EVALUATION AND ACQUISITION OF EDUCATIONAL SOFTWARE

Effects of Local Public Decision making

Forty million children are now enrolled in over 81,000 U.S. public elementary and secondary schools located in close to *16,000* public school districts. On a typical school day, over 2 million teachers work with many types of instructional materials to teach a wide variety of behavioral, intellectual, and social skills. The different needs and abilities of school children and their teachers, coupled with deeply held beliefs in universal access and local financing and decisionmaking, have gained for the American school system a reputation for participation and diversity that is unmatched anywhere in the world. This feature of our public school system is sometimes overlooked, especially by advocates of reform who focus on the ubiquitous classroom in which stu-

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dents passively digest facts and figures as they emanate from the mouth of the teacher.[23]

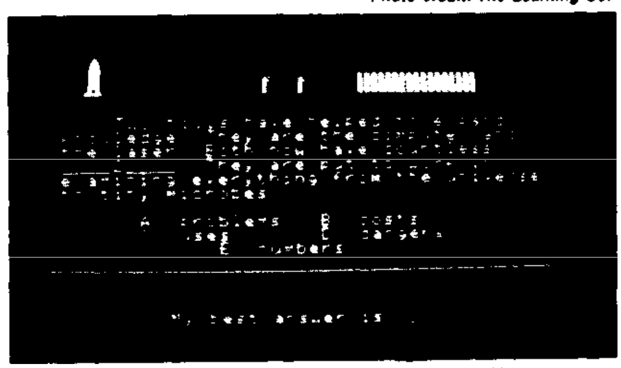
One of the consequences of this long-standing history of pluralism and local decisionmaking is that the way school systems acquire instructional materials is highly idiosyncratic. In some States, such as New York, there is no central textbook selection process. Publishers are guided by Regents examinations, which define statewide standards, and local districts choose books they believe are best suited to meeting those standards. In California and Texas, on the other hand, the State role in textbook selection and acquisition is more dominant. The combined effects of State policy, local jurisdiction, teacher preferences, and parental voice vary widely with respect to software as well. The major textbook publishers and suppliers of other instructional materials have an understanding of this market that can come only from experience, which gives them a potential edge over newcomers.

In addition to the diversity of acquisition procedures, there is also considerable variation in how school districts gather information about software products. To gain further insight into this aspect of the complex market in educational software, OTA conducted a series of open-ended interviews with computer coordinators and other personnel in school districts throughout the country .24 These interviews convey the general impression that those in charge of acquiring software seek information about competing products, that such information is available from many different sources, and that the information is fragmented and largely subjective. Indeed, the need for information upon which teachers and others can base their selections raises important policy considerations. (See box 6-D.)

Evaluation of Software Quality

Educational software, like other educational resources, can be criticized or praised on many criteria. A first cut at this problem involves the distinction between technical quality—does it work? how often does the program crash? are the screen displays clear?—and its educational quality—do children learn? are they motivated to continue learning? Rapid advances in programming experience have substantially raised the proportion of technically sound products on the market. Yet teachers continue to lament those intermittent bugs and crashes that disrupt children's learning. Although

Photo credit: The Learning Co.



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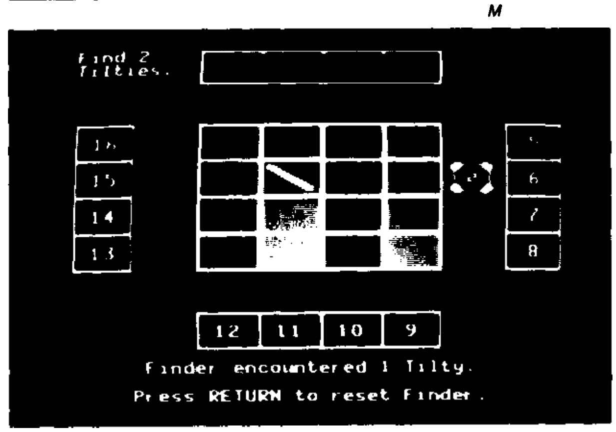


Photo credit: Sunburst Communications

Graphics, animation, and topics children find appealing are used in software to make learning feel like a game.

[23]For all their superficial similarities, American classrooms are remarkably diverse. There is considerable variation in children's achievement, and subtle differences in teacher backgrounds and styles have been proven to make a difference. Indeed, one of the most frustrating conclusions from years of education policy research is that positive results attained in one school are not easily replicated elsewhere by adopting the same apparent teaching style or curriculum. While many teachers believe they have found a successful method, most teachers recognize that there is no "one best way. " See Richard Murnane and Richard Nelson, "Production and Innovation When Techniques are Tacit: The Case of Education, "journal *of Economic Behavior and Organization,* vol. 5, 1984, pp. 353-373.

[24]For methodological detail, see Priest, op. cit., footnote 1.

Box 6-D.—Information for Software Decisions: A Sampling

- The Orange Windsor School district in South Royalton, Vermont, has been designated as the Education Resource Center for the entire State. Approximately 15 new software titles come in each week, all of which are previewed and evaluated by the same person. A grade of A, B, C, or D is assigned to each product, where the main criteria are "user friendliness," whether the product lives up to its stated goals, and whether it is a "good" educational tool. Teachers may visit the center and preview new products, for which they are charged $1 per day.
- The principal source of information about software used by the Bedford City School District in Bedford, Ohio, is the Educational Computer Consortium of Ohio. Established in 1981, the Consortium helps teachers, administrators, and parents become familiar with a wide range of educational technologies and materials. It is a nonprofit consortium, made up of 80 school districts, 7 universities, and 8 other nonprofit organizations. The resource center contains more than 100 different software packages and houses a lending library with 2-week borrowing privileges.
- The Billerica School District in Billerica, Massachusetts, is part of the 22-member Merrimack Educational Consortium. This group specializes in review of software for low achievers. Several thousand software titles are available for preview, as well as information provided by various software review organizations (such as the Educational Products Information Exchange and Digest of Software Reviews). The Consortium also publishes a review of resources targeted for adult education.
- At the Leander Independent School District in Leander, Texas, the only source of information is descriptions and reviews that appear in magazines: the district does not make use of formal evaluations. In addition, the computer instruction supervisor from the neighboring district, which is larger, offers advice. Recommendations are often made by the high school principal, assisted by a teacher, and sent up to the central district office for approval by the assistant superintendent.

SOURCES: OTA interviews with school district technology personnel; and W. Curtiss Priest, "Educational Technology: Information Networks, Markets and Innovation," OTA contractor report, September 1987.

most educators are more concerned with program content and educational effects, the costs of technical failures should not be underestimated. As the *Wall Street Journal* reported recently: ". . . corporate computer programmers now spend 80 percent of their time just repairing the software and updating it to keep it running. "[25] As educational software becomes more and more sophisticated, product reliability will become an increasingly important factor in schools' purchase decisions.

Evaluating educational effects is far more complicated than measuring technical quality of software. At one extreme, evaluation is done by academic researchers who design and conduct various sorts of experiments. Unfortunately, few of the studies to date have adhered to rigorous norms of scientific inquiry (see chapter 3). In addition, these studies typically focus on generic software types, rather than particular products. At the other extreme are the many magazines aimed at the diverse audience of computer-using teachers, most of which devote considerable space to software reviews. These reviews are invaluable, because they are usually written by computer-using teachers or by specialists in particular subject areas. But magazines are reluctant to publish negative reviews, in part for fear of alienating potential advertisers; and in selecting which of the nearly 2,000 new titles per year they will review, they are influenced by publishers' prior track records, which introduces a bias against new entrants.

In addition to magazine reviews and formal academic research, the booming educational software industry has led to the creation of a number of independent product review organizations. Many of these are private, nonprofit agencies, supported by States, universities, or school districts, individually or in consortia. (See boxes 6-E and 6-F for descriptions of two of the largest public school district and State evaluation efforts.) They use a wide range of evaluation criteria and methodologies, and serve a diverse clientele. Some, such as Educational Products Information Exchange (EPIE), attempt to include in their databases all types of software titles (although no evaluation agency catalogs every sin-

[25] *Wall Street Journal*, "Patching Up Software Occupies Programmers and Disables Systems," Jan. 22, 1988, p. 1.

Box 6-E.—Software Evaluation in New York City

In crowded offices on the fourth floor of 131 Livingston Street, across the street from the headquarters of the New York City Board of Education, a small group in the Division of Computer Information Services receive, catalog, and attempt to review almost 300 new educational software products each month. Their principal objective is to provide some systematic information about these products to a complex and diverse population of computer users. With almost 1 million enrolled children, 1,000 schools, including 32 separate school districts and 5 high school districts, the New York City school system is larger than many State systems. Last year alone, New York City spent over $4 million on software, nearly 3 percent of educational software sales nationwide.

According to Jeffrey Branzburg, a former junior high school mathematics teacher with 15 years experience and currently Special Assistant to the Director in the Office of Technology Assistance and Support for the City, over 7,000 different titles have been approved for the schools since the review process began in 1982. Who are the reviewers? They are mostly teachers, assistant principals, and principals, who are "on-call" for after school and weekend work, and who have some experience and training in software review. All reviewers have worked for major review organizations (like the Education Products Information Exchange), or have taken college-level courses in software evaluation (Teachers' College at Columbia University, Bank Street College of Education, and other institutions have begun offering credit-bearing courses in software review).

As Branzburg recognizes: ". . . software is very subjective, almost like movies, and it's difficult to be scientific. But we still feel that it's important to communicate to teachers what their peers' reactions to different products are."

Indeed, New York's highly decentralized system, the result of a bitter struggle that took place in the late-1960s, is reflected in their approach to software evaluation. Irwin Kaufman, who heads the division, points out that while the central board sets standards, districts are encouraged to do their own purchasing depending on specific needs: "LOGO might work fine in one school setting, but CAI may be best for another. It would be a big mistake to force all the different classes and kids in this system to use the same software."

Kaufman sees three main tasks for his operation: weed out the software that is racist, sexist, or otherwise unacceptable; offer teachers a variety of opportunities to try out a wide range of software products before using them in class; and negotiate hard with publishers and distributors for the best prices.

In addition to circulating a printed list of approved titles, the division maintains an on-line database, accessible via telephone and modem, with current approved titles and brief descriptions; a lending library with a large sample of software that teachers can take home; and technical assistance centers located throughout the five boroughs where teachers learn about software and sign up for training.

SOURCE: OTA site visit and interview, 1987.

gle one). while others have special interests (such as software for the learning disabled or the handicapped). The States have also become heavily involved in their own evaluations (see below).

OTA finds that among 36 software review organizations, including those funded by State or local governments and private for-profit and nonprofit entities, there is considerable overlap in the definition of quality criteria. A complete list of the criteria includes more than 200 items, the majority of which pertain to technical characteristics rather than learning effects. (See appendix B.)[26]

[26]The checklist approach to software evaluation has been challenged because products that meet certain technical criteria do not necessarily accomplish their educational objectives. See Joanne Capper, "Computers and Learning: Do They Work? A Review of Research," OTA contractor report, January 1988. For a scientific attempt to specify criteria for software see T. Malone, "Toward a Theory of Intrinsically Motivating Instruction," *Cognitive Science,* vol. 4, 1981, which makes a more formal effort to identify ingredients of effective software.

Box 6-F.—Software Evaluation in California

The State of California early on recognized the need to provide systematic information about educational software to a vast and complex school system. With over 1,000 public school districts, more than 7,500 schools, and close to 4.2 million enrolled students, the stakes are high; allocation of educational resources has always been viewed as a high-priority governmental activity.

Funding from the comprehensive State educational reform bill S.B. 813 supported a variety of initiatives, including the establishment of the Teacher Education and Computer (TEC) Center Software Library and Clearinghouse in 1982. The following year, under the leadership of Ann Lathrop and her staff at the San Mateo County Office of Education, representatives from a number of agencies across the Nation met at the first California TEC Center Software Evaluation Forum. The Consortium that emerged from this meeting has met each year since, with the principal objective of selecting software titles to be included in the *Educational Software Preview Guide*. While California holds the copyright on the *Guide*, participating agencies are encouraged to make its information available to their own local and State audiences. The *Guide* is intended to assist educators in locating software for preview. It is not intended to endorse products for purchase without examination. Thus, the underlying principle is to inform educators of their choices and to help them learn about products before adopting them for classroom use.

On another front, the State developed *Guidelines for Educational Software in California Schools* in 1985, designed with two main goals: to suggest criteria for software evaluation and to provide direction to educational software developers about State expectations for instructional technologies.

As a natural outgrowth of these *Guidelines*, the Technology in the Curriculum (TIC) Projects were commissioned in 1985, with the following objectives: to establish quality standards and content specifications for the production of software materials that would meet specific curricular needs; to broaden the scope in order to include video programs as well as conventional computer software; and to provide a resource to California educators in the selection of appropriate technological materials for classroom use. This effort—staffed primarily by teams of school teachers—focused at first on six major areas of the curriculum—English/language arts, foreign languages, history/social science, mathematics, science, and visual/performing arts. Resource guides, which are updated periodically, include annotated listings of available software programs that are compatible with curriculum objectives.

According to Wendy Harris, who has been instrumental in developing and supporting many of these activities during her tenure as Director of Technology in the Superintendent's office: ". . . the high cost of providing the service that the TIC guides represent, as well as the inevitable lag in timely review and distribution of information about new programs via conventional print media, are issues whose resolution remain a challenge."

SOURCE: OTA site visit and interviews, 1987.

One of the obvious problems of quality evaluation is that there are many instances of tool software not designed for instructional use that have yielded surprisingly good learning and motivational results in classrooms. Word processing packages, for example, originally designed for home and office use, were quickly found to create new and exciting ways for children and teachers to write, edit, and publish school newspapers. Database programs have been applied to science subjects as well as to classroom management; spreadsheets have made strong tools for teaching basic business subjects; and even games have been found to be effective. But many educators question the value of some of the more popular packages: speaking at a national conference of software publishers, one senior marketing executive said that ". . . what we don't need are more programs that print invitations and make banners. . . ."[27] In a similar vein, the assistant coordinator for technology at a large suburban school district has argued that we send children to school

[27]Phil Miller, Scholastic, Inc., speaking at the Tandy/Radio Shack Software Publishers Workshop, Fort Worth, TX, April 1987.

". . . to read, write, learn how to communicate, learn how to develop an argument, and how to get along with people," goals that will not be advanced with many of the easy and fun programs on the market today .[28]

OTA tried to compare the different formal review mechanisms that are designed to help prospective teachers and other users. As shown in table 6-9, reviews vary as to their emphasis on the following criteria:

- basic program data, i.e., whether a review gives intended age and grade range, a clear statement of the product's educational goals, type of software (drill, tutorial, simulation);
- reliability, meaning the independence of the reviewing agency and the extent to which its ratings are free from promotional considerations;
- evaluative information, meaning primarily the extent to which measurement biases are eliminated;
- number of programs reviewed;
- timeliness, measured as the number of months that typically pass between a product's release and the publication of an evaluation; and
- accessibility considerations, including the organization's familiarity, its costs for reviewing products, its circulation, and its availability.

In order to develop a composite statement about the quality of educational software, OTA also aggregated the findings of eight evaluation agencies whose criteria and review procedures seemed to provide a reasonable estimate of the state of the software supply .[29]

According to data from these agencies, nearly 60 percent of the reviewed software products are "high quality." However, it is important to point out that of the roughly **7,300** titles in the EPIE database, only 21 percent, or about 1,550 titles, were reviewed by one or more of the eight agencies. Thus, it is difficult to assess what fraction of all available software would pass muster under the evaluative criteria employed by these agencies. Even these selected agencies can be faulted for not adequately incorporating evaluators' field test results, and most reviews provide only partial information about implementation strategies adopted by teachers.

More important than these gross aggregates are subject area breakdowns. (See table 6-8.) In particu-

[28] Charles Philipp, Montgomery County Schools, MD, in Office of Technology Assessment, op. cit., footnote 14.

[29] See Bialo and Sivin, op. cit., footnote 1.

Table 6-8.—Educational Software Titles Reviewed and Recommended'

Subject	Number reviewed	Number recommended	Percent recommended
Business	35	23	66
Comprehensive skills	69	53	77
Computers	58	40	69
Early learning/preschool	61	25	41
English/language arts	169	103	61
Fine arts	54	41	76
Foreign language	56	36	64
Logic/problem solving	58	44	76
Mathematics	457	223	49
Reading	194	100	52
Science	267	176	66
Social science	102	73	72
Other[b]	90	56	62
All subjects	1,550[c]	915[c]	59

[a] Based on evaluations of educational software published through July 1987 from eight selected agencies: Alberta (Canada) Department of Education, Curriculum Branch Computer Courseware Clearinghouse; Connecticut Special Network for Software Evaluation; Educational Products Information Exchange Institute; Florida Center for Instructional Computing, High Scope Educational Research Foundations; Microsift, Northwest Regional Laboratory; North Carolina Department of Public Instruction, Media Evaluation Services; York University (Canada) YESSUS Project.

[b] The Other category combines nine subjects (agriculture, aviation, driver education, guidance, health, home economics, industrial arts, library skills, and physical education), each having less than 35 programs reviewed.

[c] The sum of the programs in the "Number Recommended" column and in the "Number Reviewed" column is greater than N because some programs were assigned to more than one subject category. All percentages were rounded to the nearest unit.

SOURCE: Office of Technology Assessment, 1987.

Table 6-9.-Educational Software Information Sources: Typology

Source type	Basic program data	Evaluation information	Number of programs	Timeliness	Familiarity with source	Circulation	Cost per year	Availability
Independent evaluation agencies	Moderately complete Reliability: high	Always provided Level of detail: high Field testing: sometimes Bias: low	50-500+	6-12 month lag	Low-moderate	5,000 or less	Ranges from no charge to $275	Low
Independent directories	Moderately complete Reliability: moderate-high	Always provided Level of detail: low Field testing: sometimes Bias: low-moderate	200-7,500 +	3-12 month lag	Low	3,000-10,000	$20-$75	Low
Professional journals	Moderately complete Reliability: high	Rarely-sometimes provided Level of detail: moderate-high Field testing: sometimes Bias: low-moderate	10-125+	8-16 month lag	Moderate	5,000-160,000	$15-$50	Low-moderate
Popular educational computing magazines	Moderately complete Reliability: moderate-high	Always provided Level of detail: moderate-high Field testing: sometimes Bias: low-moderate	250-400	2-12 month lag	High	45,000-82,000	$16-$24	High
Advertisements	Ranges from incomplete to moderately complete	Sometimes provided Level of detail: low Field testing: rarely Bias: high	200 and up; varies widely	No lag	High	Varies widely	Not applicable	High
Catalogs	Moderately complete Reliability: low-moderate	Sometimes provided Level of detail: low Field testing: rarely Bias: high	10-500+	Ranges from no lag to 12-month lag	High	Varies widely	No charge	High
Word of mouth	Ranges from incomplete to complete Reliability: low-high	Always provided Level of detail: low-high Field testing: sometimes Bias: low-high	Varies widely	Lag varies widely	High	5-500+	Ranges from no charge to $300+	High

SOURCE: Ellen Bialo and Jay Sivin, "An Analysis of the Scope and Quality of the Current Supply of Educational Software, and of the Available Sources of Information on Educational Software," OTA contractor report, Sept. 30, 1987 lar, the percentage of recommended programs varies significantly, from 41 percent in the early learning category to 77 percent in the comprehensive category (for example, tools and multipurpose programs). Furthermore, among the major subject areas, there appears to be an inverse relation between quantity and quality: although mathematics programs are the most abundant, less than one-half are "high quality." Social sciences, which constitute the lowest proportion of titles for major subjects (see table 6-2), are very well represented in quality terms. Similarly, new science programs, which have dropped in number since 1985, receive relatively good ratings. Indeed, the overall quality picture seems to be improving, especially if one considers changes in the percentage of recommended programs since 1985, as shown in figure 6-2.[30]

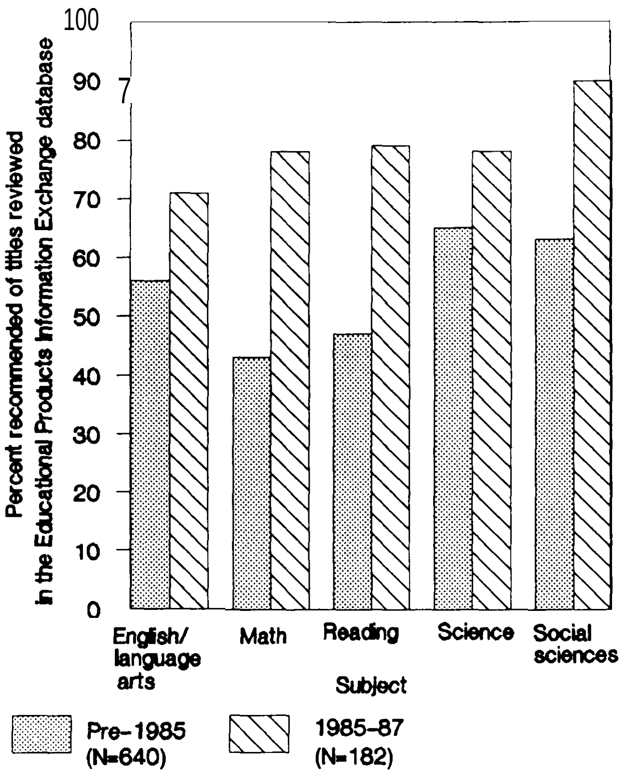
The software of most ILSs is not typically evaluated by independent review organizations or in the professional press because it is too costly to set up an entire system and test it in classroom settings. EPIE has recently begun to evaluate segments of some integrated systems, but their findings are preliminary. School districts acquiring such systems rely primarily on information contained in competitive proposals. Proposals contain information on a number of factors including correlation of software materials with district instructional objectives, cost per pupil for various configurations, and examples of how the systems have been used in other districts. Those charged with evaluating competitive bids may also conduct site visits to other school districts that are already using these systems.

The opinions of computer-using teachers can be useful indicators of software quality. As the penultimate consumers, their views are often the most credible, even if their assessments do not conform to rigorous methodology. Computer-using teachers are usually months ahead of formal reviewing agencies, who undoubtedly base their choice of which products to review at least partly on the suggestion of active teachers.

[30]Note that the sample of titles that include a copyright date is a small fraction of the total, raising questions of inference and generalizability.

In loosely structured interviews with 12 "leading edge" teachers, OTA found that they listed some 115 "best" programs. Most were characterized as "open-ended," allowing students substantial range of choices and decisions, and/or allowing the teacher considerable latitude to adapt program content to the needs of their particular student population. The highest percentage of named programs were in the "comprehensive" category (multipurpose tools rather than structured curriculum-specific software). About half the programs named by these select teachers were also rated highly by the eight formal evaluation groups; those not included by these organizations were primarily in the tool category (including graphics and other utilities), suggesting an important difference between the opinions of "experts" and the opinions of "expert teachers."

Figure 6-2.— Recommended Software Titles Before and After 1985[a]



SOURCE: Office of Technology Assessment, based on contractor's analysis of data in the Educational Products Information Exchange, July 1987.

THE STATES AND SOFTWARE

According to a 1987 survey by *Electronic Learning* magazine, 37 States operate software preview centers and 32 support software evaluation.[31] OTA expanded on this survey and obtained responses to a detailed questionnaire from all of the 50 States and the District of Columbia.[32] State efforts vary, Some States collect and evaluate software independently, others are members of consortia, and some make available evaluations conducted by nongovernmental agencies. In Arizona, for example, staff from the State Department of Education evaluate software under guidelines developed with faculty at Arizona State University. Connecticut provides partial funding for six regional education centers, which receive additional support from local districts. These centers provide a range of educational services, including software preview. Washington State does not evaluate software, but provides curriculum guidelines for educators and runs a network of technical assistance, training, and preview centers. California has been a leader in software review efforts, as well as in evaluation and technical assistance (see box 6-F).

Some States have joined together in collaborative evaluation and dissemination efforts. Project Software Evaluation Exchange Dissemination (SEED) is coordinated by the Southeastern Education Improvement Laboratory. SEED facilitates and coordinates the evaluation of software for six Southeastern States (Alabama, Florida, Georgia, Mississippi, North Carolina, and South Carolina). Participating States distribute evaluations independently to local school districts. Another consortia effort was launched in 1983 by the Council of Chief State School Officers (CCSSO). With funding from the National Institute of Education, CCSSO provided States on-line information about educational technology products (including software), gathered data about State curriculum requirements, and established links between the Federal Government, the States, and other organizations involved in educational technology. While this project, called the National Technology Leadership Project, was terminated in 1986 due to lack of funds, CCSSO has remained interested in educational technology and has been exploring new funding possibilities.

In addition to these review and evaluation efforts, 18 States fund or offer technical assistance to instructional software development projects.[33] Project IMPAC in Arkansas is a notable example, in which a comprehensive effort to match software and basic skills has been supported by business and industry and coordinated by the State. Project Vision in Kentucky, a pilot program supported by IBM and tested in eight sites, uses videodisc to teach basic mathematics skills to children in grades K-2. The software is based on the Kentucky Essential Skills, and was designed by a former teacher working as a technology consultant to the State. Because the software is developed in-house, the original cost of $10,000 per site has been cut to about $6,000.

One of the more ambitious efforts by a State to stimulate quality software development is currently underway in California. As already mentioned, one of the results of the Technology in the Curriculum Projects, started in 1984, was the identification of areas in the California curriculum for which there was little or no quality software (including video programming). Papers were subsequently commissioned to provide recommendations for software development in mathematics, science, history/social science, and English/language arts. The State then developed a request for proposals, and last year awarded development grants for six projects in mathematics, science, and history/social science. (No English/language arts projects were supported, because reviewers felt that the proposals were inadequate.) Under the terms of the program, publishers of the software retain the copyright, while the State receives a royalty

[31] *Electronic Learning*, "Educational Technology 1987, a Report on EL's Seventh Annual Survey of the States," vol. 7, No. 2, October 1987.

[32] OTA State Educational Technology Survey, 1987. Many States provided additional information and supporting documentation. For further derail, see app. A.

[33] The States are Arkansas, California, Connecticut, Delaware, Florida, Kentucky, Massachusetts, Minnesota, Nebraska, New York, North Carolina, North Dakota, Ohio, Oregon, Pennsylvania, Texas, Utah, and West Virginia.

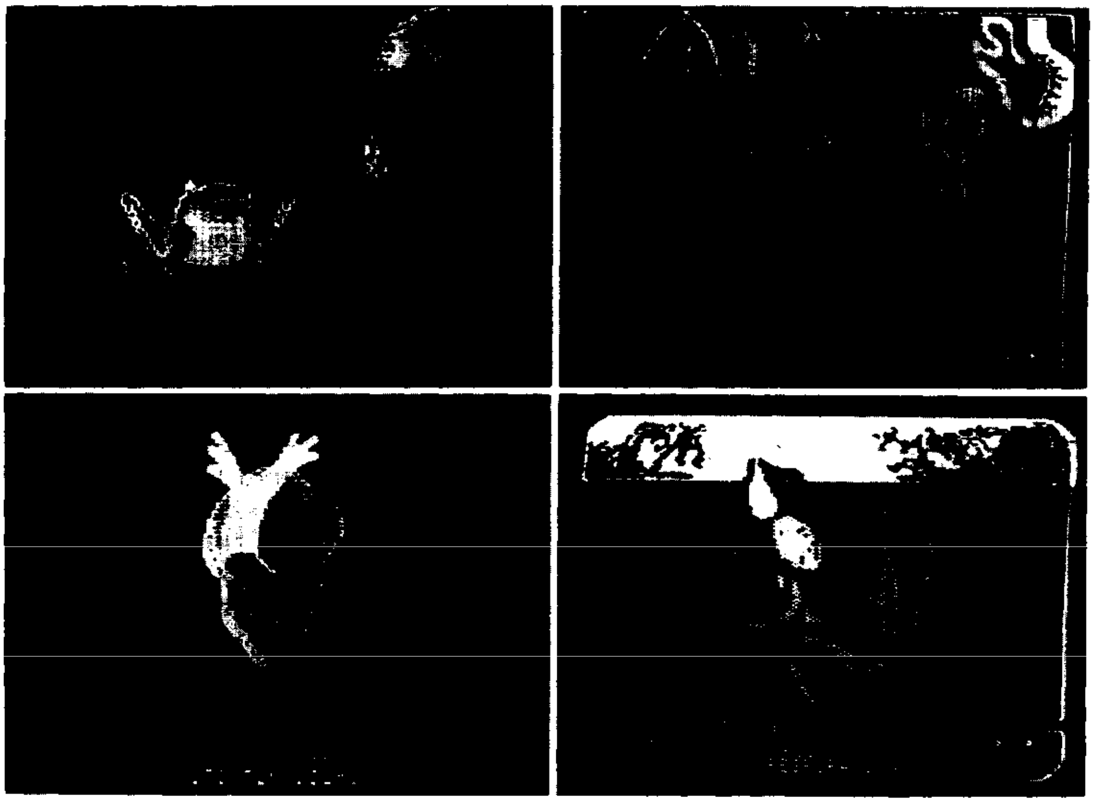


Photo credit: Scholastic Software

With an interactive computer simulation of a frog dissection, students use the computer to probe, snip, remove, and examine organs; then they attempt to replace them in the right order.

as well as the right to purchase the product at reduced cost. The royalty funds are intended to provide seed money for continued State activity. The State committed over $1 million to this effort. State officials found that despite the State's willingness to subsidize upfront development costs, few small developers submitted bids. One explanation is that the request for proposals stipulated that developers —not the State—would be responsible for marketing, the high costs of which posed a barrier to developers who were not already well established in the market. In addition, State officials believe that States will find it impossible to sustain this type of development effort unless they group themselves in consortia or receive additional outside funding. The cost of developing comprehensive software packages, for example, would exceed most States' resources.

PUBLIC POLICY; ISSUES AND DIRECTIONS

Assuming there is general agreement that computers and related technologies can play an important role in enlarging and enriching the school experiences of children, an overarching public policy question becomes how to best stimulate continued **production and use of high quality software. Indeed, since** most of the **hardware** used by schools is generic—computers are multipurpose machines—the "educational" part of "educational technology" really means software.

OTA **finds a general consensus among de. velopers, publishers, educators, and other users that the quality of available educational software**

is not as high as it might be. Moreover, despite the appearance of an active commercial market, the ability of the private sector to continue to produce and market innovative programs over the long-run, and to achieve the promise of new interactive learning tools, is uncertain.

Capital Limitations

The current national average of 1 computer per 30 children represents a small fraction of most school budgets. For a medium-sized district with 1,800 enrolled children, for example, the cost of providing 60 desktop computers is roughly $90,000, or less than 1.5 percent of the average district budget.[34] Indeed, some school districts that began installing interactive technologies in the late 1970s and early 1980s hardly noticed the expense.[35]

The problem, however, is that this level of expenditure translates to very limited instructional use of the technologies. Most computer-using students still spend only about 1 hour per week with the computer, which means that the demand for software is too low to allow most publishers to recoup their development and marketing costs. Consider the proportion of enrolled students in a given grade who study a given subject, and among them, the proportion with regular access to computers. It is clear that software publishers face a severely fragmented demand that can seldom justify the level of investment necessary to create products for those subjects and grade levels.

Property Rights

In addition to the capital limitations, software innovation is constrained by problems of *appropriability*.[36] It is difficult (or impossible) for innovators to recoup investments in products that become public goods. This is a familiar problem in education where, for example, one determinant of the quality and diversity of textbooks is the ease with which new ideas can be copied.[37] It is also a familiar problem in the general software market, where both theft of innovation (the idea for a software design or interface) and unauthorized duplication of discs have plagued the industry.

Information Barriers and Transaction Costs

This chapter earlier described various sources of information about software, and suggested that despite a great many available reviews and evaluations, purchasers of instructional software often act on imperfect knowledge. (Some would claim that it is the *overabundance* of information that complicates decisionmaking.) But software consumers are not alone in making choices with incomplete information. On the supply side, too, design and marketing decisions would be considerably more efficient if producers had better market information. One study identified four characteristics of the U.S. school system that erect barriers to information: informal acquisition decisions by teachers, principals, and parent associations which are not necessarily aligned with formal mechanisms and funding; adoption processes that vary from district to district and State to State; the inadequacy of the installed base of hardware coupled with the presence of many different computers that run different operating systems; and a fragmented market with a diverse student population taking many different subjects at different grade levels.[38]

The high costs of marketing are perceived as a critical problem in the industry. As shown in figure 6-3, over half of all software firms responding to a recent survey cited sales and marketing costs as the factor most affecting profitability. Moreover, it is important to note that this problem does not affect all firms equally. Textbook publishers and multiproduct firms are least victimized by the complexities of educational marketing. The former group, especially those with substantial market share who

[34]This estimate is based on the assumption of $1,500 per computer, which may be high, given the possibility of volume discounts. The district budget figure is based on the national average of $3,449 per enrolled child. U.S. Department of Education, Center for Education Statistics, *Digest of Education Statistics* (Washington, DC: 1987). See also ch. 6 for a more detailed discussion of costs.

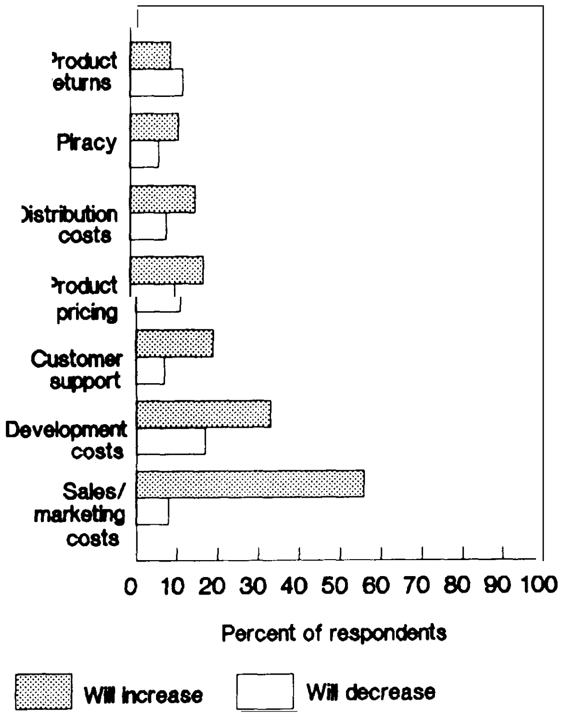
[35]George Ridler, associate superintendent for administration, Prince Georges County Public Schools, MD, Interview, Feb. 18, 1988.

[36]Appropriability is the term used by economists generally for an investor's ability to recoup returns, and specifically in the context of inventors recouping the development costs of their Inventions.

[37]See Goldstein, op. cit., footnote 17.

[38]See Henry Levin and Gail Meister, Stanford University, Center for Educational Research at Stanford, "Educational Technology and Computers: Promises, Promises, Always Promises," Project Report No. 85-A13, November 1985.

Figure 6.3.—Software Publishers' Expectations of Factors Affecting Future Profitability



SOURCE: Office of Technology Assessment, based on data from TALMIS, 1987.

have been selling books and other materials to schools for a long time, enjoy a significant advantage because of their sales networks and intimate knowledge of local acquisition policies; and even these firms must devote a considerable fraction of their budgets to marketing. By comparison, new entrants need substantial time to catch up and familiarize themselves with the best distribution and sales channels. The balance sheet of a small software developer, shown in table 6-10, illustrates the relatively high proportion of total expenses allocated to marketing.

Policy Responses

Federal policy with respect to educational software must be sensitive to the broader context of educational achievement: indeed, the great appeal of new instructional technologies lies in their potential role in raising academic performance. But academic performance depends on many factors, and not just on the level of expenditures on specific instructional materials. More computers and more software alone

Table 6-10.–"Self-Starter Software Co." Income Statement, 1986

Income:		
Cost of sales	$ (3,049.88)	
Cost of sales (computer equipment)	(3,060.00)	
Total cost of sales	(6,109.88)	
Total net sales	5,445.89	
Services (Joan)	8,459.49	
Services (David)	1,420.64	
Commissions earned	228,88	
Miscellaneous	1,032.52	
Other income and services	11,141.53	
Gross income		$ 16,587.42
Operating expenses:		
Advertising	**$5,171.34**	
Accounting and legal	**162.00**	
Automotive expenses	**1,216.12**	
Bank charges	151.88	
Electronic communications	95.38	
Depreciation	5,669.10	
Dues and publications	339.67	
Donations	39.50	
Entertainment and promotion	**396.77**	
Insurance	**782.92**	
Interest expense	*832.88*	
Miscellaneous expense	17.27	
Office expense	239,22	
Postage	**322.01**	
Repairs and maintenance	**215.97**	
Computer maintenance	20.00	
Supplies: general	63.71	
Office supplies	354.87	
Tax and license	214.40	
Telephone	1,292.60	
Travel	770.16	
Gas and electric	143.14	
Water	37.38	
Total expenses		$ (18,548.29)
Marketing expenses as percent of total:		49 percent
Net profit		$ (1,960.87)

NOTE: Items in bold considered marketing expenses.

SOURCE: These are actual data from a small software publisher in California. The name has been changed to preserve confidentiality.

are not likely to bring about significant improvements in children's learning and achievement. Decisions about educational technology generally, and software in particular, need to be sensitive to how the new tools will affect-and how their use will be affected by—the management and organization of schools.[39] In this context, OTA finds that the Fed-

[39]An example of an important school organizational issue is "autonomy": the degree to which schools are free from external political influence, and the degree to which teachers are encouraged to pursue lesson plans without stringent accountability to governmental authorities. See, for example, John Chubb, "Why the Current Wave of School Reform Will Fail," *The Public Interest, No. 90,* winter 1988, p. 36; and Carnegie Forum on Education and the Economy, *A Nation Prepared: Teachers for the 21st Century,* Report of the Task Force on Teaching as a Profession (New York, NY: 1986).

eral Government can respond to problems in the educational software market through a set of complementary strategies, as outlined below.

Technology Push

As described earlier, the combination of insufficient demand, unauthorized duplication, and theft of innovation make investments in new software very risky and may ultimately exclude all but the largest (or luckiest) players from the market. By subsidizing development costs, the government could improve the calculus of investment and returns, and provide partial relief. This "technology-push" strategy would be expected to result in a greater number of developers competing, and in a higher propensity to experiment with innovative software concepts.[40]

While the concept of providing Federal monies is separate from the question of how to distribute those monies, institutional features should not be overlooked. The ultimate success of this type of policy depends in part on the ability of the funding agency to judge the quality of project proposals, estimate their likelihood of commercial success, and allocate resources accordingly. The Federal Government has in the past supported several excellent development efforts through the Departments of Defense and Education and the National Science Foundation (see chapter 7). Although the distinction between basic and applied research in educational software is fuzzy, federally funded projects have tended toward the former. Most advocates of Federal support caution against involvement with product design and development, while they urge a steady support of basic research.

The trade-off implicit in this discussion is between the level of funding and the ability to *target* the funds effectively. The Federal Government clearly has resources and could afford to support the most qualified and sophisticated researchers. But it is poorly situated to judge the effects of various instructional tools on classroom teaching and learning.

A variation on the Federal technology-push strategy would involve joint Federal/State funding. Many States have already proven their interest and ability to stimulate software development, as discussed earlier. The principal obstacle standing in their way has been fluctuations in funding, which is often subject to changing political climates and regional economic shifts.[41] To overcome these obstacles the Federal Government could partially subsidize State and local development efforts. Local agencies would retain responsibility for curriculum definition, identification of software needs, and screening of project proposals, and their efforts would be backed by the assurance of continued Federal support.

Note, however, that even State-level software decisions may be insensitive to local needs, and may undermine efforts to grant teachers greater autonomy in classroom decisionmaking. Ideally, therefore, Federal and State resources could support local or school-level software development. This strategy necessarily implies a heightened willingness to recognize school and classroom idiosyncrasies, and to approach software development through classroom trial and error. The underlying idea is to help schools and teachers build greater instructional capacity, and not to reduce that capacity by mandating software standards from high in the educational bureaucracy. (The problem with this approach, though, is that it does not necessarily overcome fragmented demand.)

Market Pull

The complement to technology push is "market pull." As explained earlier, a principal cause of fragmented demand for software is the quantity of computer hardware in the schools and the degree of utilization. If more students had more access, it is reasonable to expect that more software developers would compete in the market. But the history of hardware acquisition by schools and school districts offers ample evidence of the power of local funding constraints and annual budget processes. Even the impressive growth in the number of schools with computers, and the dramatic reduction in the ratio of students to computers, pale in comparison to the rate at which business firms and other organizations have adopted the new technologies.

To remedy this aspect of the problem, the Federal Government could support the purchase of

[40] See also Levin and Meister, op. cit., footnote 38.

[41] The recent experiences of Texas and California are illustrative. See, for example, LeRoy Finkel, "Obituary: Teacher Education and Computer Centers (TECCS): July 1, 1982-July 7, 1987," *CUE Newsletter*, vol. 10, No. 1, September 1987. See also app. A.

hardware in sufficient quantity to improve software developers' chances of recouping their investments.[42] Again, the analogy with industry is illustrative: with office automation both widespread and intensive, incentives to software developers have led to a viable commercial market.[43] Here, too, caution should be exercised so that Federal support for hardware purchase not be perceived as Federal domination over hardware choices.

It is important to emphasize that technology push and market pull are complementary strategies. A radical increase in hardware, without assurance of appropriate **software, would be risky.**[44] **On the** other hand, Federal support for software research and development (R&D) coupled with stimulation of demand for the outputs of that R&D could be mutually reinforcing.

Portability

As mentioned previously, an additional complication software developers face stems from the incompatibility of various computer operating systems. A program written for the Apple line of computers, for example, does not work in IBM and MS-DOS machines. Thus, if all schools adopted a standard computer, software development costs would decrease significantly. However, the choice of a standard might interrupt research and experimentation on the hardware side, and might lock schools into systems that meet short-term goals at the expense of longer-term progress.

An alternative is to continue funding research on software "portability": standardized codes to make programs written in any programming language compatible with more than one operating system. This issue has been high on the research agenda of the Department of Defense, because of incompatibilities between computer-based training systems in the various uniformed services.[45] There **is a clear** Federal role in the development of portability: most computer manufacturers and software companies do not have the resources necessary to support this research, and none of them have the incentive to invest individually in a product that will benefit the industry as a whole.

Copyright Enforcement[46]

According to conventional economic analysis, unauthorized duplication of computer software (and other products that are easily copied, such as television broadcasts) causes producers to suffer economic loss, creates entry barriers to new developers, and threatens the long-run supply of new products. Stringent copyright enforcement, on the other hand, causes underutilization, because would-be copiers who cannot pay the market price for originals forego use of the product altogether. Recent extensions to the theory of copyright, however, suggest a more complex picture,[47] with implications for Federal policy toward educational software copyright infringements.

The relationship between property rights enforcement and underutilization is ambiguous. Under some conditions increased enforcement does not necessarily lead to greater underutilization. For example, if the costs of copying are already close to the market price for originals, then strengthening enforcement could induce copiers to purchase originals rather than forego usage. There is a similar type of ambiguity with respect to producers' losses: if individuals value originals largely because they can be copied–as in the case of taping television broadcasts for later viewing—then the prevention of copying could lead to reduced demand for originals.

Enforcement costs are another issue. In addition to the expenses of litigation, there is evidence that

[42] This policy is a variation on government procurement as a vehicle to stimulate demand.

[43] The French experience with Minitel, a highly successful videotex system, is a good example of how government purchase of hardware leads to a strong private sector supply of software. See, for example, U.S. Congress, Office of Technology Assessment, *International Competition in Services*, OTA-ITE-328 (Washington, DC: U.S. Government Printing Office, July 1987), pp. 172-173; and Steven J. Marcus, "The French Videotex Connection," *Issues in Science and Technology*, vol. 4, No. 1, fall 1987, pp. 108-112.

[44] Experience with other instructional technologies, such as film and television, suggest how important it is to concentrate on software. See for example, Larry Cuban, *Teachers and Machines* (New York: Columbia University Teachers College, 1986).

[45] See, for example, Dexter Fletcher, Institute for Defense Analyses, "An Approach to Achieving Courseware Portability," internal memorandum, February 1988.

[46] For a comprehensive treatment of copyright see U.S. Congress, Office of Technology Assessment, *Intellectual Property Rights in an Age of Electronics and information*, OTA-CIT-302 (Washington, DC: U.S. Government Printing Office, April 1986).

[47] See especially Ian Novos and Michael Waldman, "The Emergence of Copying Technologies: What Have We Learned?" *Contemporary Policy Issues*, vol. 5, July 1987, pp. 34-43; and Ian Novos and Michael Waldman, "The Effects of Increased Copyright Protection: An Analytic Approach," *Journal of Political Economy*, April 1984, pp. 236-246.

educational software publishers are reluctant to bring lawsuits against schools for fear of losing their principal customers (teachers can easily switch to other less expensive materials).

These issues point to the need for greater empirical investigation as a basis for government policy. OTA finds that the Federal Government could support research on these subjects, and could facilitate joint efforts by States, publishers, and school personnel to arrive at new agreements on software duplication and distribution.[48]

Firm Size and Market Structure

It is unlikely that any single policy will solve the problem of appropriability and guarantee innovators sufficient returns to their investments. To some extent, this problem is related to questions of firm size and market share: larger firms may have greater capacity for risk-bearing, but smaller firms may foster a greater enthusiasm for creativity.[49] In the absence of any magical firm size and market concentration ratio, a range of organizational and market structures should be allowed to coexist. The government could monitor shifts in these variables, for example, by examining the effects of mergers among instructional software publishers; and there should be an openness to experimenting with new organizational forms, such as joint development ventures and research consortia.

Information

A combination of actions undertaken by the Federal Government can play an important role in alleviating information barriers that impede the software market. To help on the demand side, the government could consider new efforts to collect and review software evaluation data, while supporting or incorporating existing State-level efforts and disseminating that information to school districts and user groups. For the supply side, information about State curriculum requirements would be particularly beneficial to new entrants in the software market.

[48] A model currently under consideration by Educom, a consortium of colleges and universities participating in academic software development, may be a basis on which to develop effective pricing and distribution mechanisms for the K-12 market.

[49] The trade-off is at the core of industrial organization research. See Kamien and Schwartz, op. cit., footnote 13. The authors studied many industries (but nor educational technology) and conclude that ". . . inventive activity does not typically increase faster with firm size, except in the chemical industry . . . [and] research and development activity . . . appears to increase with firm size up to a point and level off or decline." Accounting explicitly for the effects of bureaucratic organization leads to the finding that size alone cannot account for innovative capacity. See Oliver Williamson, *Markets and Hierarchies* (New York, NY: Free Press, 1975); or R. Nelson and S. Winter, "The Schumpeterian Tradeoffs Revisited," *American Economic Review*, vol. 72, No. 1, March 1982.

Summary of Policy Directions

A challenge of educational technology is to devise incentives for the development of innovative software while encouraging continued and widespread use in the schools of new and existing products. OTA believes the Federal Government could:

- continue to fund a wide range of basic research on learning and interactive software, including both advanced laboratory-based research and field studies of the effects of various software designs in real school situations;
- provide incentives to the States to subsidize software developers' front-end costs and to identify superior software designs for instructional use;
- provide money to States, school districts, and schools, independently or in consortia, to study curriculum needs, define goals for interactive media, and stimulate demand;
- discourage the formation of politicized software adoption mechanisms that may inhibit innovation and lead to homogeneity in the software supply;
- provide money to States and school districts for the purchase of additional hardware, as a means to stimulate new software production;
- support national and/or regional evaluations of software that provide commensurable data on program content, process, and measured learning effects;
- support collection and dissemination of data on school district acquisition policies and curriculum requirements;
- encourage publishers and school officials to craft mutually beneficial policies on software duplication; and
- explore innovative alternatives to strict copyright enforcement, including (but not limited to) site-licensing and State purchase of copyrights.

Chapter 7

Research and Development: Past Support, Promising Directions

Photo credit: Charles Babbage Institute, University of Minnesota

The ENIAC (Electronic Numerical Integrator and Automatic Computer), circa 1946.

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Chapter 7

Research and Development: Past Support, Promising Directions

INTRODUCTION

American education is at a crucial juncture. The demands on schooling in our pluralistic society are greater than they have ever been. An increasing percentage of students are educationally at risk, and demographic projections make clear that this problem will continue to grow. In addition, schools must prepare all young people with a new set of skills and understandings to assure the Nation's economic competitiveness. At the same time, technology makes it possible to consider real improvements in the productivity of both teaching and learning. Taken together, these forces could change what is taught, when it is taught, how it is taught, and the nature of teaching as a profession.[1] **Because of the great promise offered by interactive technologies for learning, Congress needs to consider a substantial Federal investment in research and development (R&D) to exploit more fully the power and potential of technology for education.**

In the past, education has been at the far end of the information technology R&D pipeline. Ideas have taken up to 20 years to move from basic research to school application. Although the technology is changing rapidly, current policies inhibit the flow of ideas along the continuum from research to development, evaluation, and dissemination. Many barriers block this flow. They include the absence of a coordinated Federal policy, limited and short-term funding, erratic political support, and disorganized R&D efforts across agencies. As a result, many opportunities have been delayed; others may have been lost altogether.

[1] See U.S. Congress, Office of Technology Assessment, *Technology and the American Economic Transition: Choices for the Future,* OTA-TET-283 (Washington, DC: U.S. Government Printing Office, May 1988), pp. 47-49.

FINDINGS

- Public education K-12 is a $150 billion a year business. The Federal Government spends not even 0.1 percent of that amount on research to improve it.
- The Department of Education's $128 million share of the $63 billion fiscal year 1988 Federal R&D budget amounts to 0.2 percent of all Federal R&D. And the Department of Education's own budget devotes less than 0.5 percent to research.
- Funding for educational technology R&D has been inconsistent over the last 30 years. Educational priorities have been buffeted by the winds of political change, making long-term commitments rare.
- With no lead agency for educational technology R&D and no structure for coordinating activities across agencies, there has been no strategic planning, little long-term evaluation, and missed opportunity for transferring findings across agencies with similar research interests. Despite these difficulties, some of the best educational technology products in use in schools today are the outcomes of Federal investments in R&D since the 1960s.
- Military agencies provided approximately three-quarters of all funding for educational technology research over the last three decades, supporting much of the early work on computer-assisted instruction (CAI), cognition, and simulation for

skills training. Research in artificial intelligence and advanced computing applications continues to be important for education, but military research may no longer be the patron of such work.

- Where civilian R&D finding for educational technology has been focused and consistent, the investment has produced important results. Examples include technology to improve educational opportunities for the handicapped and learning disabled; development of public broadcasting facilities and innovative children's programming, from *Sesame Street* to *Square One TV;* and the development of LOGO, a computer programming language for children.

Research in cognitive science, allied with developments in computer-based technology, the installed base of technology in the schools, and teachers willing to experiment create today's "window of opportunity" for improving education. R&D seeding could bear fruit. Among the most promising new research developments are:

- Intelligent tutoring systems that can make the services of an expert and responsive tutor regularly available to the learner.
- Applications that exploit the computer as a flexible multimedia controller, enhancing curriculum with the richness of video, graphic, and audio representations of information.
- Simulations, microworlds, and exploratory laboratory experiences in all disciplines that enable students to gain understanding through exploration, manipulation, and guided discovery.
- Integrated tools and "intelligence extenders" that help students to move beyond low-level tasks and concentrate instead on more cognitively demanding learning and problem solving.
- New assessment measures that track learning, diagnose students' conceptual understandings, and evaluate the attainment of nontrivial skills.
- Design tools, authoring systems, and knowledge kits that enable teachers to create and shape their own teaching materials, to modify curriculum, or develop individualized lessons for their students.
- New curriculum based on a changing vision of the skills students need in the information age, shifting much of the emphasis from what *to learn* to *how to learn.*

Promising developments require closer ties between the research community and the classroom and contributions from many fields.

- A new dialog must be established among teachers, researchers, and school administrators to tie classroom needs and realities to promising research findings and technology applications. Without close ties between the laboratory, the design facility, and the classroom, technology that is needed may not be developed; that which is developed may not be adopted or successfully used by teachers.
- Educational technology R&D requires interdisciplinary research, pulling together expertise in cognitive science, artificial intelligence, computer science, anthropology and sociology, psychology, instructional design, and education. Interdisciplinary researchers are in short supply, and their research requires stable, long-term investments, to support advanced hardware and software and to sustain projects from prototype development to evaluation in real school settings.

OTA concludes that the Federal Government must play a much greater role in supporting and coordinating research, development, and demonstration in educational technology. While the States and local districts can and will support some aspects of technology implementation, and private industry should continue to play a role, neither the States, the districts, nor the private sector has the capacity or incentive to conduct long-term research, promote comprehensive development, or disseminate promising results.

EDUCATION AND R&D: A NATIONAL PERSPECTIVE

The national investment in education and training is huge. As a nation we spend somewhere in the range of $300 to $500 billion a year on all types of education and training, in schools and in industry.[2] About $150 billion of that is spent by States, localities, and the Federal Government on public education. The Department of Education's budget request for fiscal year 1989 is $21.2 billion.

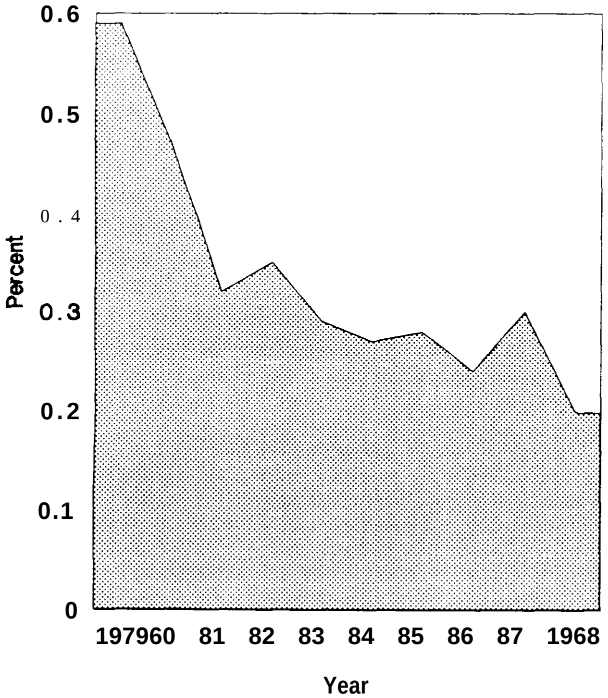
R&D is also a major investment. The United States currently invests over $120 billion per year, just under 3 percent of the gross national product, in public and private R&D. The Federal Government share of R&D is $63 billion, 62 percent of which is military R&D. Education R&D commands less than 0.1 percent of the Federal R&D budget (see figure 7-1). Since 1980, funding for education R&D has decreased dramatically, while both Federal and overall spending for education increased.[1] Moreover the National Institute of Education's expenditures for research have decreased since the early 1970s by more than 70 percent in constant dollars at the same time that the overall Federal investment in education increased by 38 percent[4] (see figure 7-2a and b).

[2]Ibid., p. 47.

[3]See U.S. Congress, Congressional Research Service, U.S. *Department of Education: Major Program Trends, Fiscal Years 1980-89*, Report 88-330 EPW (Washington, DC: April 1988), pp. 97-100; and U.S. Congress, General Accounting Office, *R&D Funding: The Department of Education in Perspective*, Report PEMD-88-18FS (Washington, DC: May 1988).

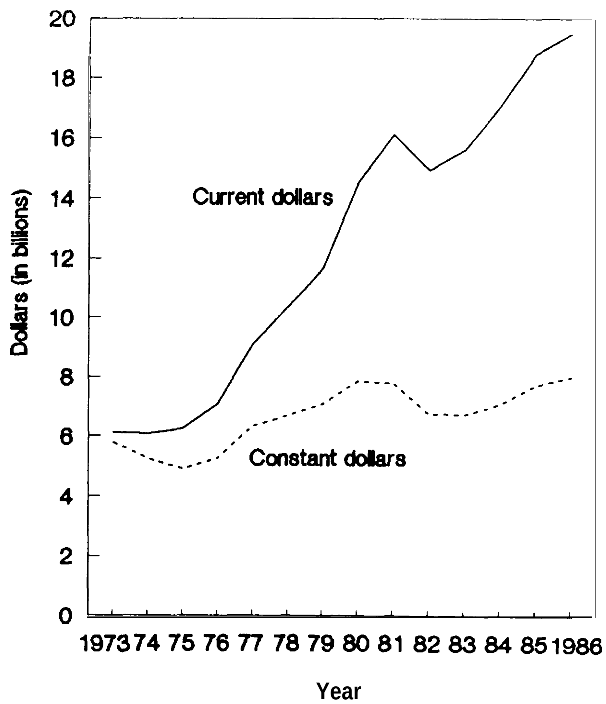
[4]For a fuller analysis, see U.S. Congress, General Accounting Office, *Education Information: Changes in Funds and Priorities Have Affected Production and Quality*, Report PEMD 88-4 (Washington, DC: November 1987).

Figure 7-1.—Obligations for R&D in the U.S. Department of Education as a Percent of All Federal R&D Obligations, 1979-88



SOURCE Office of Technology Assessment, based on National Science Foundation, "Federal Funds for Research and Development," detailed statistical tables, 1987.

Figure 7-2a.—U.S. Department of Education Obligations in Current and Constant 1972 Dollars for Fiscal Years 1973-86[a]



[a]Includes the Office of Planning, Budget, and Evaluation, the National Center for Educational Statistics, and the National Institute of Education. Constant 1972 dollars are computed by using the implicit price deflator for federal Government purchases of goods and services as reported in Survey of Current Business.

SOURCE: US. Congress, General Accounting Office, "Education Information, Changes in Funds and Priorities Have Affected Production and Quality," Report to the Chairman, Subcommittee on Select Education, House Committee on Education and Labor, November 1987,

FEDERAL SUPPORT FOR EDUCATIONAL TECHNOLOGY R&D[5]

It is exceedingly difficult to isolate and quantify the exact amount the Federal Government invests in R&D for educational technology. Expenditures are fragmented among and across departments, agencies, bureaus, offices, and programs. It is even harder to trace these funds over the years, because of reorganizations and shifts at all levels of government. OTA's estimate of Federal support for educational technology R&D is based on an analysis of the three agencies that have been the major funders in this area: the Department of Defense (DoD), the National Science Foundation (NSF), and the Office of Education/Department of Education. **Direct Federal funding for R&D which impacts educational technology accounts for total spending of approximately $240 million per year,[6] never approaching the billions committed to other major categories of technology-related R&D, such as energy, agriculture or transportation.**

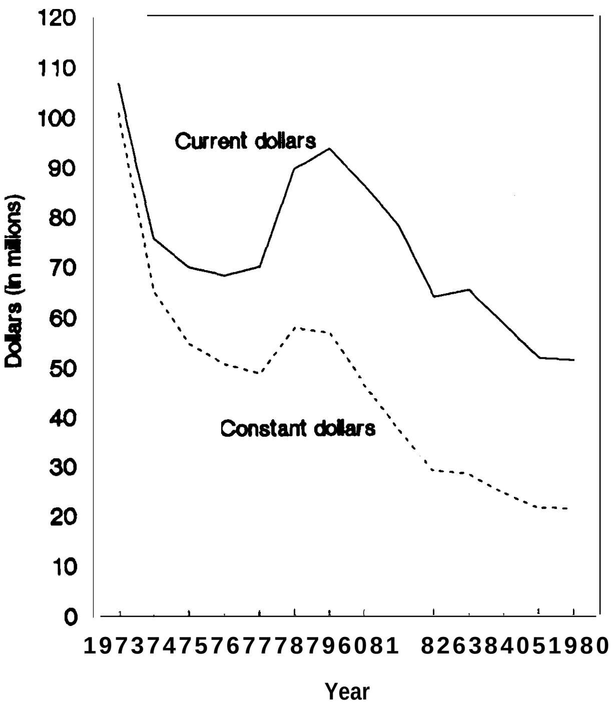
The Department of Defense

DoD has played a major role in the development of computer technology and its applications to education and training. In fact, one of the earliest technologies, the chalkboard, was created at West Point. An instructor, Frenchman Claude Crozet, found himself in a dilemma. Unable to speak English and with no textbooks to teach his science course, he painted a wall of his classroom black and wrote on it with chalk.[7] The computer itself was developed using defense R&D funds.

With its growing demand for technologically skilled service personnel able to maintain and operate increasingly sophisticated military equipment, DoD training requirements have increased. As noted by two military analysts:[8]

> A current and probably correct assumption behind U.S. defense planning is that in any major confrontation, ranging from deterrence to combat, our adversaries will be able to supply greater numbers of people than we can. We have sought to counter this superiority in manpower quantity with quality, partly in manpower but primarily in advanced materiel . . . faster tanks, more heavily armed aircraft, more sensitive radar and sonar, more accurate fire-control devices, more powerful and more complex computers to aid tactical and strategic decision

Figure 7-2b.—National Institute of Education Obligations in Current and Constant 1972 Dollars for Fiscal Years 1973-86[a]



[a]Constant 1972 dollars are computed by using the implicit price deflator for Federal Government purchases of goods and services as reported in Survey of Current Business.

SOURCE: U.S. Congress, General Accounting Office, "Education Information, Changes in Funds and Priorities Have Affected Production and Quality," Report to the Chairman, Subcommittee on Select Education, House Committee on Education and Labor, November 1987.

[5]This section draws heavily on Charles Blaschke et al., Education Turnkey Systems, "Support for Educational Technology R&D: The Federal Role," OTA contractor report, Sept. 30, 1987.

[6]This figure is a rough estimate that includes the Department of Defense manpower and personnel education and training research and development in technology ($207.6 million), the National Science Foundation precollege technology activities ($1 1.8 million), and the Department of Education discretionary research and development technology activities ($18. 1 million) (fiscal year 1987 figures).

[7]C. Anderson, *History of Technology 1: Technology in American Education, 1650-1900*, Occasional Paper No. 1 (Washington, DC: National Education Association, Technological Development Project, 1961); also J.R. Ollsen and V.B. Bass, "The Application of Performance Technology in the Military: 1960- 1980," *Performance and Instruction, vol. 21, 1982.*

[8]J. Dexter Fletcher and Marty Rockway, "Computer Based Training in the Military," *Military Contributions to Instructional Technology (New* York, NY: Praeger Publishers, 1986), pp. 172-173.

> making, and so on. However, we must operate, maintain, and deploy this materiel close to the limit of its intended performance. If we do not, the high cost of the materiel will be wasted, and the competitive edge it is intended to buy will be lost . . . no understanding of military systems is complete without consideration of the human performance they require to function as designed. Put another way, human performance is an inseparable, essential component of every military system. Given this perspective on military-system effectiveness, it is not surprising to discover that the military investment in training is immense.

Furthermore, as more recruits enter the Services with low reading, writing, and mathematics skills, the military has had to spend billions educating and retraining the failed products of our educational system.[9] Investments in instructional technology R&D are viewed by the military as a means of making their huge personnel education and training system more efficient,

The level of DoD's investment for education and training has consistently exceeded that of all Federal civilian agencies combined. The military now spends approximately $208 million a year on R&D technologies in education and training, while civilian spending on technology R&D for K-12 education is estimated at $30 million. Put another way, the military spends $7.00 for every dollar spent by the civilian sector on R&D for instructional technology.

DoD R&D in technology ranges from basic cognitive science investigations to applied development of course materials and electronic teaching machines. Figure 7-3 shows a timeline of representative projects supported by the services since the 1950s. Sustained efforts, combined with large levels of support for projects carried across the R&D continuum, resulted in training applications of direct utility to the military agencies. The military also explored high-risk but potentially high-payoff technology developments that reaped benefits for education (see box 7-A).

Two major lines of support can be traced over time. The first line traces research in programmed instruction leading to applications in CAI and computer-based instruction (CBI), and research in computer-managed instruction (CMI) for individualized training systems for military personnel. Examples along this line of development include:

- PLATO, envisioned as a "book with feedback" as early as 1959, and supported by combined DoD resources for numerous iterations of development.[10] An important component was a large-scale longitudinal evaluation. This evaluation and other studies of PLATO provided important lessons for developing CBI with the next generation of computers.
- The Air Force's Semi-Automatic Ground Environment for Air Defense System (SAGE), a prototype and progenitor for a host of military and civilian computer-based information systems. In designing SAGE it was found most efficient to embed training instruction directly in the system. The system taught the operator how to use it. This concept led to further development of projects utilizing computer controlled instruction in educational systems (e.g., AIRDALE, DIOGENES, and the Advanced Instructional System).
- Applications of the IBM System 1500 for CAI training. The Naval Academy used the System 1500 for CAI in physics, chemistry, Russian, and Naval Operations analysis; while the Naval Station in San Diego and the Army Signal School at Fort Monmouth, New Jersey developed CAI in electronics training.
- Research by the Office of Naval Research (ONR) and the naval laboratories on programmed instruction led to the largest CMI effort of its time, the Naval Air Station project in Memphis, serving more than 6,700 students daily.

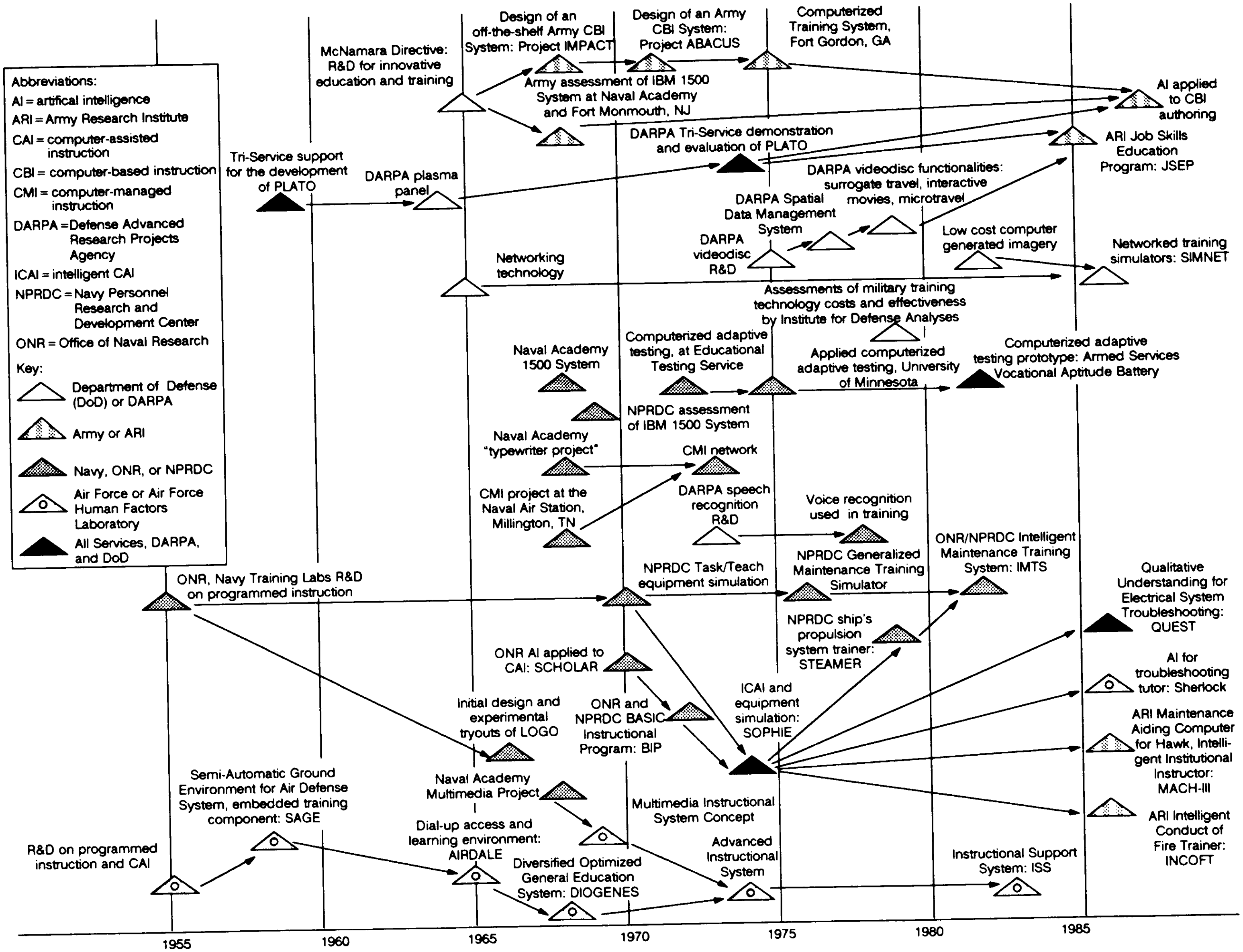
The other major line of research has led to simulations for various training applications, such as:

- Navy's Taskteach Tutorial, which simulated equipment for maintenance training and led to development of a General Maintenance Trainer/Simulator and the Sophisticated Instructional Environment (SOPHIE). SOPHIE received Tri-Service support and is considered the "mother"

[9] It has been estimated that, on an average day in 1984, some 265,000 military and civilian personnel were undergoing some type of formal training, requiring a support staff of another 194,700 personnel, at a cost of $13.3 billion for that year. Ibid., p. 173.

[10] The National Science Foundation also supported development of PLATO in the 1970s. See National Science Foundation section below.

Figure 7-3.—Timeline of Major Instructional Technology Projects in the Defense Agencies, 1955-87[a]



[a]Time-line designation indicates year of project start-up.

SOURCE: Dexter Fletcher, Institute for Defense Analyses, 1988.

Box 7-A.-The Special Characteristics and Contributions of the Defense Advanced Research Projects Agency (DARPA)

DARPA was particularly important for the development of computer technologies, many of which have been applied to education and training applications. The agency was established in 1958 in response to the Sputnik crisis, to explore high-risk but potentially high-payoff technology developments and to protect the United States against technology surprise. While most of DARPA's support focused on air missile and space defense, some observers have called it ". . . the single-most influential government agency for the development of instructionally relevant capabilities such as computer speech interaction and artificial intelligence."[1]

From 1960-75, DARPA funded a number of major projects related to computer-assisted instruction and artificial intelligence. DARPA provided funding arid served as an umbrella for support from each of the services for the PLATO project. During the late 1960s, DARPA also supported path-breaking R&D in artificial intelligence at Stanford and the Massachusetts Institute of Technology. Other developments focused on applications of microprocessor-controlled videodisc technology, such as interactive movies, surrogate travel, and low-cost visual simulators such as the tank gunnery trainer. Other DARPA contributions include developments in computer-based authoring systems, learning strategies, and skills acquisition. Research in the 1980s focused on large-scale networks, computer systems software development tools, tutoring systems, and human factors research in "embedded" training.

In the cognitive science and computer science research community, DARPA was seen as the agency most open to far-reaching ideas. Innovation was encouraged and researchers came to believe that they could walk into DARPA with an interesting idea and walk out the door with a check to try it out. Several characteristics of DARPA in the 1960s and 1970s contributed to this responsiveness:

- Procurement flexibility: Few DARPA contracts followed the traditional competitive bid process, Iargely because it was assumed that some of the expected outcomes could not be adequately prescribed in RFPs.[2]
- Management flexibility: DARPA's staffing philosophy tallowed project officers, themselves highly qualified researchers and scientists, unusual discretion and responsibility but limited their employment to relatively brief periods to minimize empire building and to cross-fertilize the government and outside R&D communities.
- Mission priority and umbrella coverage: The high priority of the DARPA mission was reflected in its position in the Department of Defense hierarchy. Its director reported directly to the Secretary of Defense. DARPA often provided seed or risk money to conceptualize an idea or initiate a small program. As an official noted "The implicit mission of DARPA was to fund important areas of R&D which the services overlooked or refused to support."[3]

Because of its flexible authority and management, DARPA was able to provide continuity, effective communications and continuous support within its R&D community. The initial development and subsequent use of ARPANET, the agency's electronic network, provided unique opportunities for those on the network to exchange information including findings, "bounce ideas off experts," "refine thinking," and test the rigor of research in process.

The long gestation period required for ideas to become useful innovations made DARPA's ongoing support extremely important. However, a recent trend toward more directed and applied R&D projects is now also reflected in DARPA funding priorities. If the research community can no longer look to a DARPA for early and consistent support of innovative concepts, the next decade's innovations may not get any further than the "interesting idea" stage.

[1] J. Dexter Fletcher and Marty Rockway, "Computer Based Training in the Military," *Military Contributions to Instructional Technology* (New York, NY: Praeger Publishers, 1986), pp. 206-207.

[2] "Revolutionary not evolutionary is supposed to characterize all DARPA projects. The agency's position is that if a project can be prescribed by a request for propoals, rhen DARPA should not be doing k." Ibid., p. 206.

[3] Marshall Farr, personal communication, August 1987.

of several other intelligent tutoring systems developed by the services for training personnel in troubleshooting tasks and equipment operation and maintenance.
- Defense Advanced Research Projects Agency (DARPA) research on videodisc technology, which led to interactive movies (allowing the student to control such aspects of viewing as perspective, detail, plot, and simultaneous action), surrogate travel (enabling the learner to "walk" through an area as it is displayed visually and to see what lies ahead or around the corner of each chosen path), microtravel (surrogate travel through places where people cannot go, as through a jeep engine while it is running), spatial data management (allowing users to "fly over" an array of information and select what they want through joystick controls), and low-cost portable simulators such as the tank gunnery trainer.

Early top-level support for R&D in educational technology came from a 1965 memorandum from then Secretary of Defense Robert McNamara to the Secretaries of the Army, Navy, and Air Force. Noting that little was being spent on innovations and new methods and techniques for education and training, the Secretary directed that a line item be placed in the budget for educational R&D ". . . to be used primarily on specific projects directed toward the improvement of existing Defense Department education and training programs."[11] His support was based on evaluations of previous CAI projects showing a 20 percent reduction in training time, the opportunity to individualize instruction, and the ability to control and manage a variety of media projects.

These evaluations of effectiveness have been important for generating ongoing support for projects. Training, in contrast to education, is relatively easy to evaluate, both because of methodology (it provides a tight feedback loop for instruction research and evaluation) and motivation (because training can be linked to specific jobs, cost-effectiveness tradeoffs are more readily and immediately observable than they are in education.)

The military services continue to support important work on basic research on cognition, artificial intelligence, speech recognition, interactive learning systems, and converging technologies. The military has been a major, and occasionally the major, player in advancing the state-of--the-art. Implications for education in the civilian sector are clear. **Computers would probably have found their way into classrooms sooner or later. But without work on PLATO, the IBM System 1500, computer-based equipment simulation, intelligent instructional systems, videodisc applications, and research on cognition, it is unlikely that the electronic revolution in education would have progressed as far and as fast as it has.**[12]

Nevertheless, there are important limitations that must be considered. First, adults, not children, are the focus of the military's training efforts. Children's needs are different. Training and education have different goals. Although skills development may have some carry-over, educational goals are more complex than the specific objectives of military training applications. Finally, although there have been civilian benefits from spinoff in technical areas, in general DoD spin-off benefiting the K-12 education community is shrinking as DoD research increasingly focuses on military applications.

As shown in table 7-1, the military's "6. 1" (basic research) budget category has remained relatively static, while funds in the "6.2" (experimental development) and "6.3" (advanced development) budget categories have grown. Furthermore, it has been suggested that less than one-third of the $25.7 million listed under 6.1 research has application to educational technology.[13] Significantly, although the amount of DoD R&D funding for instructional technology overall is considerably greater than that provided by all other agencies, no system exists to facilitate technology transfer to civilian education counterparts.[14] This continues, as it has for three decades, to be a missed opportunity.

[11] Secretary Robert S. McNamara, U.S. Department of Defense, memorandum, Aug. 16, 1965.

[12] Fletcher and Rockway, op. cit., footnote 8, p. 212.

[13] Judith Orsanu, director, Basic Research Institute, Army Research Institute, personal communication, May 1988.

[14] One official noted that one of the best, if only, mechanisms of technology transfer from the Department of Defense to civilian agencies probably comes from the fact that many researchers receive support from both sources and move freely between sponsoring agencies; Susan Chipman, personal communication, November 1987. Others have noted that informal exchange occurs more often under 6.1 funding, which typically supports university researchers, than in the case of 6.2 and 6.3 funding for applied research. These grants and contracts for experimental and applied development often go to private contractors and industry, where sharing of information is less prevalent.

Table 7-1.—Department of Defense Manpower and Training: Technology Research and Development Expenditures, 1976-87 (in millions of dollars)

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
6.1 Research	7.2	10.3	11.8	13.7	13.77	19.77	17.65	21.20	20.64	27.12	26.54	25.73
6.2 Experimental development	28.8	37.7	47.5	57.6	54.65	69.14	62.16	72.12	80.64	83.48	89.60	96.97
6.3 Advanced development	24.6	34.5	44.6	57.2	50.57	55.74	53.75	61.36	68.03	85.55	90.64	84.87
Total	60.6	82.5	103.9	128.5	118.99	144,65	133.56	154.68	169.31	196.15	206.78	207.57

SOURCE Funding levels for the years 1980-87 are supplied by the Manpower and Training Research Information System (MATRIS). The figures for 1976-79 are from the Office of the Secretary of Defense. The differences between 1979-80 may be due to some slight differences in the selection criteria and changes in program elements when MATRIS was established. The congressional categories for education and training, human factors, manpower and personnel, and simulation and training devices are included. The above figures have not been adjusted for inflation. For further detail, see Charles Blaschke et al., Education Turnkey Systems, "Support for Educational Technology R&D: The Federal Role," OTA contractor report, Sept. 30, 1987.

The National Science Foundation

NSF support has been, and continues to be, an important basis for educational technology in the schools today. Although only a small proportion of science education funds were earmarked for technology R&D at the K-12 level, this support has been critical. From 1968 to 1981, precollege technology projects received from 1 to 3 percent of NSF's science education budget. More recently, however, this proportion has changed. Since 1984, an average of 8 to 11 percent of the Science and Engineering Education (SEE) Directorate funding has supported precollege technology activities.

1968-78: The Early Years

In 1968, President Johnson issued a memorandum directing NSF to take the lead in supporting computer use in schools. NSF responded with the establishment of an Office of Computing Activities (OCA) directly responsible to the director of NSF. This high level of support was an important springboard for action. Although most of OCA's projects were at the university level,[15] 10 to 15 percent of projects supported early work in CAI and other applications of technology in elementary and secondary schools. Projects included the Huntington Two Project, to create educational materials based on computer simulations for high school biology, physics, and social studies; development of CAI materials for mathematics and reading drill and practice; and studies of the effect of CAI on teaching programming and data processing concepts to inner-city secondary school students. At this time, NSF also provided research support for a new programming language "so simple that it can be taught to second graders," which became LOGO (see box 7-B).

Support for CAI and LOGO continued when the educationally-oriented technology work moved to the newly formed SEE Directorate in 1972. New CAI projects included PLATO IV[16] and TICCIT, and the development of a computer-based high school mathematics laboratory. Much of the software for early educational computing systems came from NSF support.[17]

As the SEE Directorate suffered declining appropriations ($7 million in 1974, $5.9 million in 1975, $2.9 million in 1976), educational technology R&D support decreased as well. Nonetheless, further development, field tests, and evaluation of CAI systems continued. Other activities included support for LOGO and work on computer graphics, the development of laboratory instruments connected to microcomputers for science education, and examinations of various new telecommunication technologies for the delivery of instruction.

The decade following President Johnson's call for more research on school computer applications was an important one for educational technology despite limited funding. NSF support during this period made important and lasting contributions. Nearly

[15] These Included support of university and college regional computing networks; CONDUIT, a project supporting the transfer of computer-based learning materials and expertise across universities; and projects aimed at furthering expertise in the use of computers in specific disciplines, such as the Commission on College Physics.

[16] Over a period of 5 years, PLATO received $7.8 million in National Science Foundation funding.

[17] One analyst estimates that by 1973 over 800 of 2,750 educational software programs had been supported in part by the National Science Foundation. Beverly Hunter et al., *Learning Alternatives in U.S. Education: Where Student and Computer Meet* (Englewood Cliffs, NJ: Educational Technology Publications, 1975).

Box 7-B—The Development of LOGO

LOGO is a computer programming language designed for children. Among educational technology developments, LOGO had far reaching impact. Over two dozen versions of LOGO now exist in eight foreign language translations on 13 different types of computers. Dozens of curriculum packages and 60 books have been written on LOGO, while LOGO workshops have become a staple of preservice and inservice teacher training.

LOGO R&D received Federal support, first from the military and then the civilian sector, for more than 20 years, in spite of changing missions, budgets, and organizational structures. Researchers point to the critical role of program managers who were willing to support visionary ideas and take a long-term perspective. Projects at Massachusetts Institute of Technology (MIT) and Bolt, Beranek, and Newman (BBN) had multidisciplinary groups and collaboration among highly talented people from diverse backgrounds—developmental psychology, artificial intelligence, mathematical logic, physics, engineering, and computer science. These groups transcended traditional boundaries, even in their own institutions. At MIT, for example, the LOGO group was part of the Artificial Intelligence Laboratory which did not have a "home" in one of the traditional academic departments. Similarly, funding agents had to depart from traditional disciplinary boundaries in supporting this work.

Over the two decades of support, technology state-of-the-art changed dramatically. Each stage in LOGO's development was implemented on newer and more powerful computer systems. Researchers could take advantage of new technology capabilities at each stage because they were working in technology-rich environments that included people with expertise at the cutting edge. From the beginning, LOGO research involved work with children in classrooms. Early subjects may not have been "typical," but they provided an important connection to the real world. Currently, the Hennigan School in Boston is the site for the MIT study of the impact of LOGO microworlds in a technology intensive environment.

Chronology

1963-68: Wallace Feurzeig of BBN, contracts with the Office of Naval Research (ONR) to develop new computer systems for teaching complex concepts.

1965-66: BBN, with support from U.S. Office of Education, explores student use of TELECOMP, an interactive programming language, at eight elementary and secondary schools served by BBN time-sharing system.

1966: Feurzeig, intrigued by the results of working with children on TELECOMP, convinces ONR to let him develop a programming language for children under the ONR contract. The contract officer agrees, providing that work with children is done at a military dependents' school.

1966: Seymour Papert of MIT, Daniel Bobrow of BBN, and others work with Feurzeig on designing a procedural computer language simple enough for children to learn yet powerful enough for expressing important intellectural content. The new language, named LOGO, is based on LISP, ironically considered to be one of the most difficult of programming languages to learn.

1967: First version of LOGO used in teaching math with fifth and sixth grade students at Hanscom Field School in Lincoln, Massachusetts, with ONR support.

1968-69: LOGO-based mathematics in second, third, and seventh grades. (National Science Foundation (NSF) support for BBN was unusual since they traditionally funded only universities. But NSF became convinced that this work was important, and that only BBN could do it.)

1970-71: NSF continues support to BBN for the development of extended LOGO-based mathematics curriculum materials. LOGO-related work also funded by Air Force Office of Scientific Research on programming languages as a tool for cognitive research.

1970: BBN develops first version of LOGO for the DEC PDP-10, the computer system widely used in universities and educational research centers, and distributes it free of charge to all interested universities and research centers.

1970 to 1986: NSF continues support for LOGO at BBN, MIT, Syracuse University, New York Academy of Sciences, and other centers. But NSF support does not come easily. In the mid-1970s Science Education Directorate staff were unsure whose responsibility LOGO was: mathematics educators did not regard LOGO as true mathematics, while computer science educators did not regard it as valid computer science.

1986 to Present: Two new versions of LOGOWriter and LegoLOGO expand the scope of applications. NSF continues to fund research applications at Lesley College, Kent State University, Carnegie-Mellon University, and other institutions.

Photo credit: LOGO Systems, Inc.

Concepts in engineering, physics, and robotics are made real as students write computer programs to operate machines they have created in LegoLOGO.

all the technological tools, pedagogues, and methodologies now widely used in education had their instructional origins in these early NSF projects—telecommunications and computer networks, graphics, speech synthesis, programming languages such as LOGO, laboratory instrumentation, instructional simulations, interactive dialogs, economics modeling and gaming, social science data analysis, interactive videodiscs, career counseling systems, and computer literacy for educators.

1978 to 1988: Commitment to Educational Technology Despite Setbacks

At the time when schools were beginning to acquire microcomputers in large numbers, NSF had no program focused on educational technology R&D per se. However, from 1977-81 approximately $1.6 million per year was targeted to technology in the Research in Science Education (RISE) and Development in Science Education (DISE) Programs in the SEE Directorate. While the research sum was small, it was significant because it supported work in cognitive science and artificial intelligence applications to instruction. This was the only research of its kind being supported outside the military. NSF officials point to this early work as seminal in the field of intelligent CAI and intelligent tutoring systems.[18]

Other activities supported by RISE and DISE included the development of computer literacy materials and studies, the use of computers to teach reasoning skills to junior high students, a study of new applied mathematics techniques using the PLATO system, development of mathematical reasoning programs for young children, and development of prototype materials for interactive videodiscs.

In 1981, the SEE Directorate was dismantled, a political event which had traumatic results for the science and technology community. Research groups were disbanded; some researchers moved into industry, some to military training, and others left the field altogether. Many observers believe it created a serious hiatus from which science education is still recovering. During this period, NSF personnel who remained made creative efforts to seek alternative means of continuing support for research in educational technology.

Two approaches were adopted: industry partnerships and interagency cooperation. Neither came easily, but both produced important results. Industry partnerships were forged under the program "Development in Science Education Involving NSF/Industry Cooperation for Science and Engineering Education Using Computers." The program encouraged universities to develop innovative prototypes of CBI materials or model programs in science and engineering education. Support was shared almost equally between NSF, industry (through donations of computer equipment), and the grantee institutions, each of whom had to provide at least one-quarter of the project cost to receive an award.[19]

The second focus was interagency cooperation. In order not to lose momentum and skilled research-

[18] Andrew R. Molnar, "Intelligent Tutors and Knowledge-Based Systems in Education," paper presented at the Conference of *Applications* of Artificial Intelligence and Expert Systems, 1986.

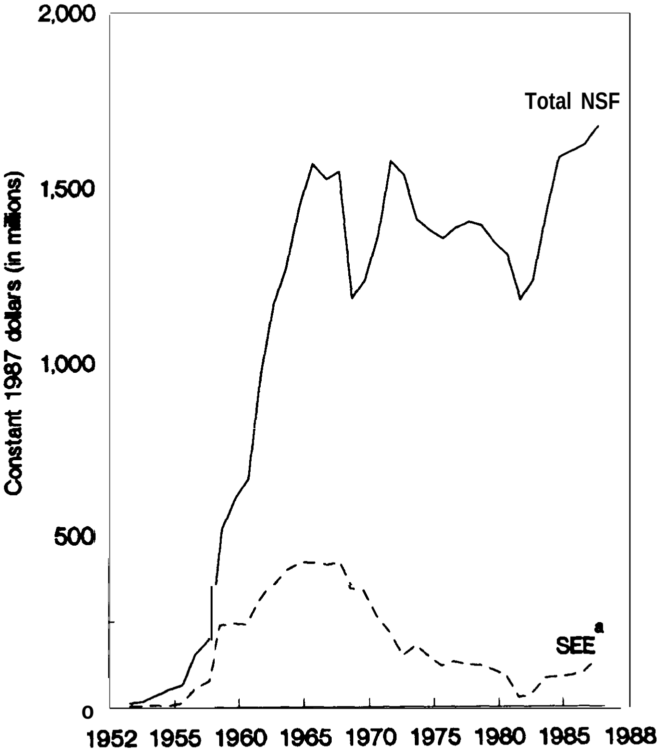
[19] Dorothy K. Deringer and Andrew R. Molnar, "University, Industry, and Federal Cooperation—A Case Study," *Science, Technology, and Human Values,* vol. *8, No.* 4, *1983,* pp. 40-45.

ers in the middle of projects, other program offices in DoD and the Department of Education picked up some of the NSF projects. For example, NSF and the National Institute of Education (NIE) provided joint funding for research on cognitive processes that provided a basis for closer relationships between cognitive science and technology. But interagency funding has its drawbacks: it is difficult to negotiate and subject to short-term support, especially if dual funding is perceived as duplication of effort rather than cooperation. NSF took this risk because the situation was desperate and interagency finding was the only way to support important work in progress.

With the reestablishment of the SEE Directorate in 1984, R&D activity in technology expanded. Funding for science and engineering education, while not yet returned to its 1968 level, has grown (see figure 7-4). A 44 percent increase for 1988 pushed NSF's education budget to $139 million, followed by a fiscal year 1989 request of $159 million. Educational technology R&D aimed at elementary and secondary education is also receiving more emphasis, now approximately 10 percent of the SEE budget. (See figure 7-5.) Four programs sponsor activity: Instructional Materials Development, Informal Science Education, Research in Learning and Teaching, and Applications of Advanced Technologies.

Several projects in the Instructional Materials Development Program are exploring alternative methods of delivering instruction via computers, videocassettes, and telecommunication technologies.

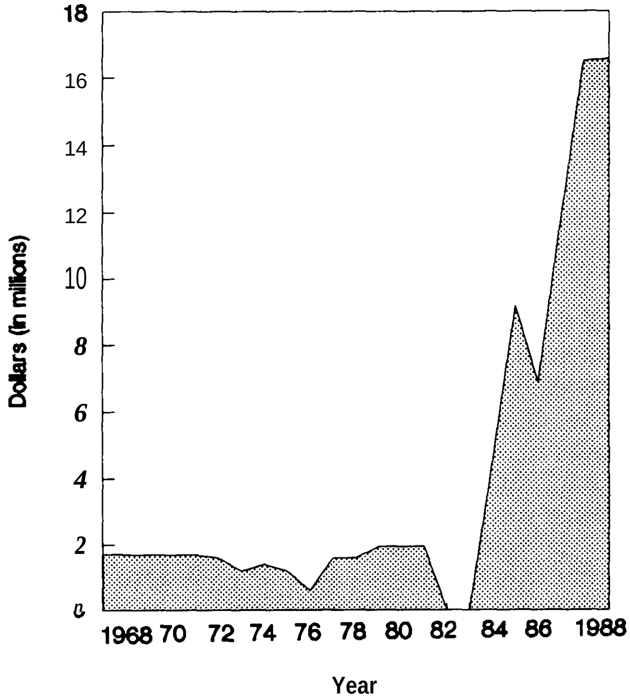
Figure 7-4.-National Science Foundation Budget, 1952-88



[a]SEE: Science and Engineering Education Directorate.

SOURCE: Michael S. Knapp et al., *Opportunities* for Strategic *Investment in K-72 Science Education: Options for the* National *Science Foundation* (Menlo Park, CA: SRI International, June 1987), vol. 2, from data supplied by NSF/SEE.

Figure 7-5.—National Science Foundation Obligations for Research and Development of Educational Technology in Elementary and Secondary Education[a]



[a]Estimates are based on the following NSF programs:

1968-71 —10°/0 of the Office of Computing Activities for elementary and secondary education

1972-76—20% of CIE and Technological Innovations in Education for elementary and secondary education

1977-76—15% of Development in Science Education and Research in Science Education

1979-61 —15°A of DISE and RISE + $333,000 joint program with NIE

1964—66-200/0 of Instructional Materials Development (IMD) + 1000/. of Advanced Applications of Technology (AAT) + $500,000/year for Research in Teaching and Learning

1987-88—NSF estimates based on IMD, AAT, and Teacher Preparation and Enhancement programs

SOURCE: Office of Technology Assessment, 1986.

The Informal Science Education Program supports several media projects, some funded jointly with the Department of Education. Television programs include *NOVA, 3-2-1 Contact!* and *Square One TV.*

The Research in Learning and Teaching Program funds several projects in cognition and studies of student difficulties in understanding concepts in science and mathematics. Computer projects include a study of the effects of computer-based curricula in school algebra; a project looking at how high school students and teachers solve problems in genetics using computer simulations; and an assessment of elementary and middle school children's LOGO debugging skills.

Examples of work supported by the Applications of Advanced Technologies include study of intelligent tutors in calculus, algebra, geometry, prealgebra, and algorithmic problem solving; creation of a computer work station for children; creation of Boxer, a new educational computing system; synthesis of research findings on key factors in science teaching and learning using instructional technology; several projects applying or extending LOGO in mathematics; and development of microcomputer-based laboratories.

Summary of NSF Impact

NSF educational technology R&D made important strides when it enjoyed periods of secure, long-term funding and when Presidential interest made it a priority. At other times herculean efforts were required to maintain and support critical research, development, demonstration, and evaluation. It took several years after the shutdown of the SEE Directorate for momentum to return. Since the first new major grants were made in 1985, results are only now beginning to percolate through the system. [20] Even with increased funding, organizational divisions inhibit the flow of research into development, and on into school demonstrations and evaluations. As one manager noted, "We fund research but have no money for development, or development with no funding for demonstration, or demonstration with no funding for field tests or evaluations."[21] It is difficult to conduct good research, to hold good Federal managers, or to attract new researchers to the field under these conditions,

Another important factor to note is that NSF's R&D has primarily influenced technology use in science and mathematics, because of NSF's mandate in these subject areas. The impact has been important for these disciplines, but educational computer applications in the humanities and arts have not benefited in equal measure. This would not be a problem if other agencies, particularly the Department of Education, were to fill in the gaps. As the next section outlines, strategic support has been lacking at the Department of Education.

Office of Education/Department of Education[22]

Education's support for educational technology spans three decades and includes efforts to develop educational television and public broadcasting facilities, to increase access to technology by enabling schools to purchase hardware and software, and to expand the base of knowledge and innovation through R&D. Support for the technology infrastructure and materials acquisition far exceeded the dollars invested in R&D.

Much of Education's finding for educational technology came from categorical programs and block grants that allowed school districts to purchase technology—televisions in the 1960s and 1970s; computers, videocassette recorders (VCRs), and software in the 1980s. Enabling schools to acquire instructional technologies creates a "bottom up" incentive for innovation and research. As the base of machines in schools grows, their use expands, driving development of new products to feed the school market. Consequently, Federal policies that encourage purchases of technology can indirectly stimulate R&D.

Education's limited spending for R&D in the area of educational technology is not surprising when one looks at the overall low priority granted education research in general. Barely half of one percent of

[20] John Walsh, "Breakthrough for Education at NSF?" *Science,* vol. 240, Apr. 15, 1988, p. 272.

[21] Andrew Molnar, National Science Foundation, personal communication, May, 1988.

[22] The Office of Education was a part of the Department of Health, Education, and Welfare until the establishment of a cabinet-level Department of Education in 1980. In this report, both organizational entities are referred to as "Education."

the Department of Education budget goes to research.[23] By comparison, the Nation spends about as much annually on health care as on education, but it spends 60 times as much on health research.[24] The military, where R&D has been increasing at an average increase of 7.8 percent per year since fiscal year 1984, devotes about 12.8 percent of its total DoD obligation to research.[25]

Of all the Federal agencies, it is most difficult to extract consistent figures on funding for educational technology from Education. Technology has been supported in various pockets of programs, often without a line item in the budget. OTA estimates that between 1961 and 1987 Education spent approximately $200 million for educational technology R&D on computer-based applications. Although a sizable total investment, given the 26-year time span, it is in fact small from the perspective of overall Federal R&D in this area. (DoD instructional technology R&D expenditures from 1971 to 1987, a 16-year time period, is over $1.9 billion.) In fact, each *year* the military spends approximately as much for R&D in educational technology as the Department has over the last 26 years.

Early Efforts

Education's largest investment in technology has been in support of public television, both through the creation of the public broadcasting infrastructure and in television programming that addresses critical educational needs. The American public and the schools are still enjoying the fruits of this investment. The Educational Broadcasting Facilities Program was created by Congress in 1962 to assist (through matching grants) in the construction of noncommercial educational television or radio broadcasting facilities. Between 1962 and 1978, when the program was transferred to the Department of Commerce, Education spent a total of $151 million on public broadcast facilities. Television and radio programming support began in 1968 with support to the Children's Television Workshop for R&D on *Sesame Street,* and continued with funds provided by the Emergency School Aid Act (ESAA), passed in 1972 to eliminate minority group segregation and discrimination. One of the activities supported by the act was the development and production of integrated children's television programs of cognitive and affective value. ESAA funds provided a total of $67 million for television series and related activities, including such series as *Villa Allegre, Vegetable Soup,* and *Infinity Factory.* Funding for television programming from 1968 to 1980 totaled $134.3 million.[26]

One of the most important changes in the Federal funding of education was the 1965 passage of the Elementary and Secondary Education Act, which focused national attention on education and provided increased financial support.[27] The "War on Poverty" looked to education as a means of creating social change, and computer-based education was seen as a potentially powerful tool for improving the educational opportunities for the disadvantaged. Time-sharing on mainframes made it economically feasible for students to begin to have access to expensive computers.

One of the best known computer-related projects supported by the Office of Education in the 1960s was Stanford University's development of instructional materials for educationally disadvantaged elementary school children. The Stanford computers in California were able to serve students as far away

[23] "This is of special concern since the Federal Government is the primary source of funding for such research, as there is no education industry investing in educational research as we find in other areas." Nancy Cole, president, American Educational Research Association, testimony before the House Committee on Education and Labor, Subcommittee on Select Education, Apr. 21, 1988.

[24] Institute for Research on Learning, *The Advancement of Learning* (Palo Alto, CA: 1988), p. 11. The expenditure on health services for 1987 is estimated at $496.6 billion in "National Health Care Expenditures, 1986-2000," in *Health Cam Financing Review*, summer 1987, p. 24. The 1987 expenditure on health research by the Department of Health and Human Services is from the 1989 fiscal year budget. Total spending on education and training at all levels is estimated at $453 billion ($ 144 billion at the elementary and secondary level, $94 billion for post-secondary, $210 billion for employee formal and informal training, and $5 billion for government training); see Anthony Carnevale, American Society of Training and Development, "The Learning Enterprise," *Training and Development Journal*, January 1986, p. 18.

[25] Richard E. Rowberg, chief, Science Policy Research Division, Congressional Research Service, testimony before the House Committee on Education and Labor, Subcommittee on Select Education, Apr. 21, 1988.

[26] Andrew A. Zucker, "Support of Educational Technology by the U.S. Department of Education: 1971 -1980," *Journal of Educational Technology Systems, vol. 10, No. 4, 1981-82,* pp. 303-320. Department of Education staff indicate that an additional $25 million was spent on educational television since 1980. Arthur Sheekey, Office of Educational Research and Improvement, U.S. Department of Education, personal communication.

[27] Overall Federal funding for education increased from $375 million in **1958** to $4.2 billion in 1968.

as Kentucky and Mississippi via telecommunications—itself a powerful demonstration of technology. An unusual financial feature of the project was the use of Title III funds, which were awarded to States and localities for services, to supplement the direct support made available to Stanford for R&D.

During the 1960s, the Office of Education also funded several significant R&D projects involving video technology, including evaluation research comparing conventional teaching and video presentations; the establishment of a video clearinghouse, the National Instructional Television Center at Indiana University, from which grew the current Agency for instructional Television (now the Agency for Instructional Technology); and support for improved capacity of public radio and television stations under the Education Broadcast Facilities Program. In 1964, NIE funded the Learning Research and Development Center (LRDC) at the University of Pittsburgh. One of LRDC's mandates was to study the potential of technology for education.

The 1970s: Educational Television, Special Education, and CAI Evaluation

In the 1970s, much of R&D continued to focus on television as an educational tool, Education also spent approximately $200 million on computer-related activities during the 1970s, of which about $50 million was for R&D, including demonstration projects. Many significant R&D projects in the Bureau of Education for the Handicapped opened new learning opportunities for the handicapped. These projects included closed captioning of television, enabling the deaf to have access to a substantial portion of television programming for the first time; development of the OPTACON for the blind, a device which produces images of printed letters using small, raised, vibrating wires; and support for the development of the Kurzweil reading machine, another device for the blind, which scans text and reads text aloud through synthesized voice technology. Subsequent funding supported dissemination of these devices. The Bureau of Education for the Handicapped also supported a computerized database on instructional materials for the handicapped; studies of reading and mathematics CAI materials for deaf and hearing impaired students; and demonstrations of electronic mail for communication with the deaf.

Other technology programs during this period included several applications of telecommunications for education: the Educational Telecommunications for Alaska project, which provided the scattered and small Alaskan schools with electronic mail, CAI, and other services via microcomputers; and the Appalachian Community Service Network, which used satellite distribution of instructional programming.

Research on the effectiveness of CBI, as well as development and evaluation of computer software was also begun. Projects included an extensive 5-year longitudinal study of the effectiveness of CAI in the Los Angeles public schools, conducted by the Educational Testing Service; an educational software review and distribution service for school districts (MicroSIFT) under contract to the Northwest Regional Laboratory; and development of software in mathematics (Ohio State University), writing (Bolt, Berenek & Newman), and language arts (WICAT). Products created by these software development projects were made available for commercial distribution and were used by schools. In addition, development of a multimedia science and mathematics program series for children that included broadcast television, computer software, and videodisc materials was funded through a multiyear award to the Bank Street College of Education for the creation of the *Voyage of the Mimi.*[28]

Early 1980s: Block Grants, Computers, and a Technology Initiative

As computers became widely available, there was great excitement surrounding them; *Time* magazine chose the personal computer as "Man of the Year" for 1982. Schools no longer had to purchase large, expensive systems in order to use computer technology; they could buy as many or as few computers as they could afford. Parent-Teacher Associations bought them for schools as fast as bake sale proceeds came in. Federal Chapter 2 funds also became an important resource.[29]

[28]Additional funding was provided by the National Science Foundation in subsequent years. This was due in part to efforts by Department of Education program managers who, recognizing the need for additional funding beyond Department of Education allocation, turned to their colleagues in the National Science Foundation for help.

[29]The Education Consolidation and Improvement Act of 1981 consolidated discretionary grant programs into block grants that were directed to the States and local jurisdictions through formula fund-

(continued next page)

Where separate authorizing legislation existed, and where program managers had a commitment to technology, the Department continued to fund technology R&D activities.[30] From 1981 to 1987, an estimated $129 million was spent on educational technology R&D and demonstration projects with computers.[31] The Office of Special Education and Rehabilitative Services continued studies of computer use for handicapped students, with followup projects that developed a variety of applications including hardware, adaptive devices, and special education software. Dissemination efforts were designed to bring research findings and development efforts to schools and the special education community. Additional studies were conducted in the Office of Vocational and Adult Education and in NIE, but most were not given adequate support to move beyond research into development, classroom trial and evaluation, and dissemination, particularly after a shift in Department research priorities after 1984.

The Department of Education began its participation in the congressionally-mandated Small Business Innovation Research (SBIR) Program in 1983. The SBIR Program is aimed at accelerating the commercialization of new devices developed under government support. With funding levels that are based on a percentage of the agency's overall external R&D budget, SBIR grants were awarded for technological innovation in areas proposed by the Offices of Special Education, Vocational Education, and Educational Research.

Several computer projects were supported by the Department of Education in the early 1980s under the Secretary's "Technology Initiative."[32] Although not a new funding initiative, this effort signaled Secretary Bell's support for technology through a variety of programs under existing authorities within the Office of Educational Research and Improvement (OERI). Among these were 12 technology demonstration projects where computer applications were studied and showcased; studies of the availability and quality of software in reading, mathematics, sciences, and foreign languages; and continuing support for *The Voyage of the Mimi* television series and accompanying computer materials, and for two other educational television series, *3-2-1 Contact* and *Spaces.*

The Department sponsored a research conference in November 1982 on the potential of computers for education.[33] Recommendations made by the distinguished group of experts from the fields of artificial intelligence, cognitive science, and education provided a conceptual framework for the Depart-

(continued from previous page)

ing. These funds (Chapter 2), distributed on the basis of the number of students, were to be used for educational improvements as the States and districts saw fit. Many districts used their block grant monies to purchase computer hardware and software. Chapter 2 and its predecessor programs have provided about $510 million for computers and related expenditures. A study of the Chapter 2 block grant program showed that, for the third year of block grants (1984-85), support for computer applications was the most popular activity, accounting for 30 percent of all local expenditures under block grants. During this same period, 72 percent of the Nation's schools used Chapter 2 for computer-related purchases. Michael S. Knapp et al., *The Education Block Grant at the Local Level: The Implementation of Chapter 2 of the Education Consolidation and Improvement Act in Districts and Schools* (Menlo Park, CA: SRI International, January 1986).

'For a full list of these projects, see Susan Klein, *Computer Education: A Catalog of Projects Sponsored by the U.S. Department of Education* (Washington, DC: U.S. Department of Education, 1983). One example was the Title VII 3-year grant awarded to the Seattle Public Schools to develop computer-assisted instruction in U.S. history for Vietnamese, Cambodian, and Laotian high school students. See U.S. Congress, Office of Technology Assessment, "Trends and Status of Computers in Schools: Use in Chapter 1 Programs and Use With Limited English Proficient Students," staff paper, March 1987, pp. 86-87, box B.

[31]OTA extrapolation, based on Klein, op. cit., footnote 30.

[32]U.S. Department of Education, "Fourth Update on Technology Initiative Activities," internal memorandum, Jan. 18, 1984.

[33]Alan Lesgold and Frederick Reif, *Computers in Education: Realizing the Potential*, Report of a Research Conference (Washington, DC: U.S. Department of Education, August 1983).

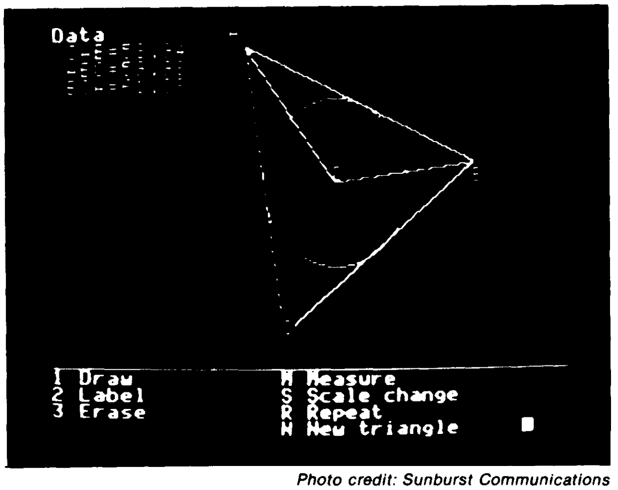


Photo credit: Sunburst Communications

In the *Geometric Supposer*, developed with Federal funds, students can manipulate geometric shapes to test and apply theorems.

ment's technology research agenda, and were included in planning the competition for a Department-sponsored Educational Technology Center. A nationwide competition for the center was held, and the award was made to the Harvard Graduate School of Education, funded at $7.7 million over 5 years to conduct R&D on the role of technology in teaching mathematics, science, and computing. The center focused on "targets of difficulty," curricular topics that are both critical to students' further progress in these fields, and widely recognized as difficult concepts to teach and learn. Various research projects at the center studied the nature of students' difficulties in understanding, exploited the educational capabilities offered by computer-based technology, and designed experimental lessons using computers as well as traditional materials to address these difficult topics. Teams made up of researchers from the center and participating classroom teachers tried out some of these promising units in local high schools to learn how they worked in the classroom.[34]

As part of a plan to increase Department of Education involvement in educational technology, Secretary Bell created a National Task Force on Technology in 1983, ". . . to investigate the potential of appropriately integrated technology to improve learning in our nation's schools."[35] It was Bell's hope that this Task Force would set a national agenda for educational technology.

1984 to Present: A Lower Priority for Technology

When Secretary Bell left the Department of Education in 1984, the technology initiative and related emphasis on computer activities ground to a near halt. The new Secretary, William Bennett, did not share Bell's vision of improving education through technology. The climate in the Department, reflected partly in the declining number of new grants involving computers, shifted significantly.

Illustrative of Bennett's lack of interest in technology is the Department's response to *Transforming American Education: Reducing the Risk to The Nation,* the report to the Secretary by the National Task Force on Educational Technology, referred to above. Unlike *A Nation At Risk,* which was released at a special ceremony at the White House and given major nationwide distribution and publicity, the technology report was held several months and eventually released but not printed or made available to the public through the normal Government Printing Office channels.

The reductions in computer-related R&D were especially notable in the obligations of OERI, which was not bound by the legislative mandates as is the case in the Office of Special Education[36] or the Office of Post-Secondary Education. OERI, which took over the National Institute of Education in 1984, has a more open charter and is therefore more responsive to general priorities in elementary/secondary education established by the Secretary and Assistant Secretary. The trend is displayed in several ways. A recent computer printout listing OERI technology projects supported since 1980 illustrates how many were supported in the early 1980s and how many fewer have been started since 1983.[37] Another change is in support for R&D projects of long duration. In the 1970s, the Department supported quite a few projects lasting 5 or more years (e.g., the longitudinal study of CAI in Los Angeles, development of closed captioning of television, the Kurzweil reader, and the *OPTACON).* During the 1980s, few projects received comparable long-term support. Finally, the number of research grants to individual researchers decreased substantially.[38] While this decrease affected educational research as a whole, projects with a technology orientation were particularly notable by their absence.[39]

Summary of Department of Education's Impact

The Department of Education has had an off and on love affair with technology. Where research support has been consistent, as in support of children's

[34] Educational Technology Center, Harvard Graduate School of Education, "Making Sense of the Future," a position paper on the role of technology in science, mathematics, and computing education, January 1988, p. 1.

[35] National Task Force on Educational Technology, "Transforming American Education: Reducing Risk to the Nation," a report to the Secretary of Education, unpublished manuscript, April 1986.

[36] A detailed discussion of the various programs and projects for the handicapped and others with special needs can be found in Blaschke et al., op. cit., footnote 5.

[37] Sheekey, op. cit., footnote 26.

[38] General Accounting Office, op. cit., footnote 3.

[39] Of the nine grants to Field-Initiated Research Studies funded in fiscal year 1987, one had a technology focus. Sally Kilgore, director, Office of Research, Department of Education, letter to colleagues, May 13, 1988.

television programming in the late 1960s through the 1970s, or long term as in support for technology in special education, important milestones were reached. These are the exceptions. Most research projects did not have opportunities to proceed from laboratory research through to development of products and processes, much less to testing in the classroom, with real students and teachers.

Other Agency Support for Educational Technology R&D

Other Federal agencies have also supported research that has or could ultimately lead to innovations in education. The National Institutes of Health supports medical research that includes studies on the brain and the way it functions. The Department of Labor has numerous manpower training and retraining programs that use technology to help workers enter the labor force or to adjust to changes in required job skills. The State Department and the Agency for International Development have language and other training programs and have applied computer-based technologies to improve these education activities. The National Aeronautics and Space Administration (NASA) spends approximatley $8 million a year in artificial intelligence research; R&D on human-machine interfaces in the areas of vehicle control and space station applications are

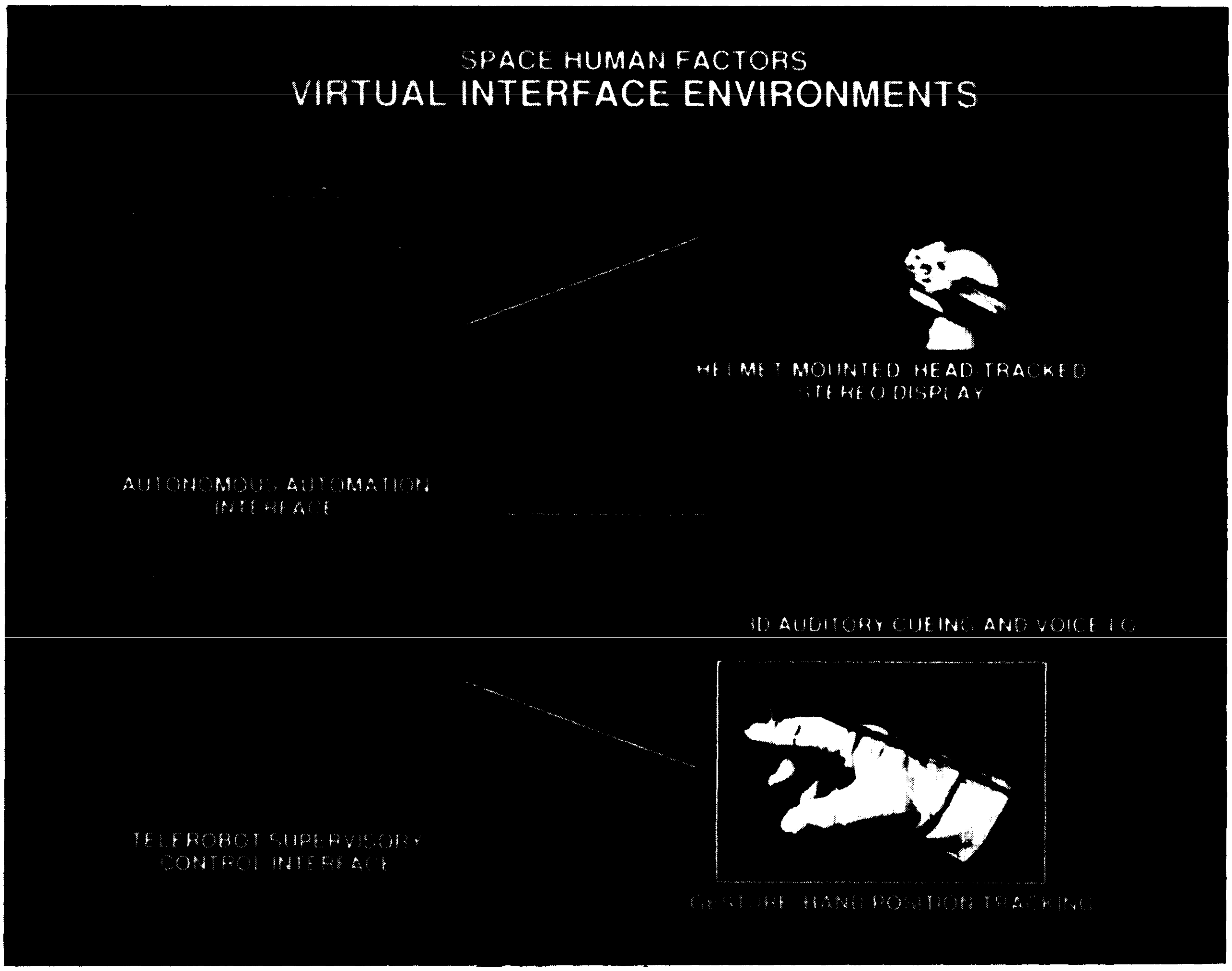


Photo credit: National Aeronautics and Space Administration, Ames Research Center

How can technology research conducted by other Federal agencies be applied to benefit education?

in addition to this funding[40] (see box 7-C). NASA also has an extensive education program in astronomy and space sciences, and has developed software and videodisc materials for schools, and satellite broadcasts and telelectures for teacher education.[41]

These and other government-supported R&D programs contribute information and innovations to the area of educational technology, but it is difficult to identify the most promising projects for education or to measure the cumulative level of funding or impact. Project goals and priorities are targeted to each agency's mission, and are not generally considered for potential applications in schools. Typically, these agencies share a common problem with the Department of Education, NSF, and DoD—the lack of enthusiasm or support for technology transfer within programs in house or across agencies.

Box 7-C.--NASA's Intelligent Computer. Aided Training: Spinoff for Schools

At the Johnson Space Center, NASA researchers are conducting research in the area of expert systems in advanced physics and astronomy for use in flight training modules. They are also developing a tutoring system using CLIPS, an authoring language which subject matter specialists can use to write their own tutoring programs. Both these projects have applications for education, and the researchers at NASA are looking for ways to share their findings with the Texas schools. Because NASA has a technology utilization program whose mandate is to encourage technology transfer to civilian and industrial programs, there is funding to facilitate this research spinoff to schools. The projected cost of applying the research toward the development and school-based testing of a high school physics course which uses intelligent tutoring software is approximately $1.3 million.

[40] Melvin D. Montemerlo, Office of Aeronautics Space Technology, Division of Information Sciences and Human Factors, National Aeronautics and Space Administration, personal communication, March 1988.

[41] National Aeronautics and Space Administration, Educational Affairs Division, Office of External Relations, *Educational Affairs Plan: A Five-Year Strategy FY* 1988-1992 (Washington, DC: October 1987).

CURRENT FEDERAL PRIORITIES

Although the military, through DARPA, ONR, and the Service laboratories, has been a major contributor to basic research in technologies that have later led to educational developments, both Federal officials and researchers suggest that this may no longer be the case. Overall funding for basic research in DoD has received a smaller share of the Defense R&D budget as big ticket items falling into the 6.2 and 6.3 categories of exploratory and advanced development take a bigger bite (see table 7-2). Furthermore, present research priorities preclude projects in cognitive science that have an education, rather than training, orientation. Many fear that the pipeline for innovative developments for education will suffer from the lack of support from a once powerful funding patron, the military R&D agencies.

Educational technology research at NSF, however, is on the upswing. As shown in table 7-3, the fiscal year 1989 budget request for precollege technology efforts is 61 percent higher than that for fiscal year 1987. As noted above, however, NSF's focus is predominantly on mathematics, science, and computer

Table 7-2.—Department of Defense Research and Development Funding, 1984-89[a] (in billions of dollars)

	Fiscal year					
	1984	1985	1986	1987	1988	1989[b]
Research , , .,	0.84	0.85	0.95	0.89	0.90	0.92
Exploratory development,	2.22	2.27	2.28	2.34	2.39	2,36
Advanced development[c].,	1.41	2.70	4,07	5,03	5.43	6,51
(SDI) , .,,,....	(0.05)	(1.39)	(2.66)	(3.26)	(3,53)	(4.52)
Other ., ...	22.27	25.28	26.20	27,82	29.17	29,09
Total. ., . .	26.76	31.10	33.50	36.09	37.90	38.87

[a] Data provided by the Office of the Secretary of Defense.
[b] Current administration request.
[c] Includes funding for the Strategic Defense Initiative (SDI).

SOURCE: Richard Rowberg, Chief, Science Policy Research Division, Congressional Research Service, testimony before the House Committee on Education and Labor, Subcommittee on Select Education, Apr 21, 1988.

programming. The Department of Education, which has responsibility for research in broader areas related to education, has just recently begun to again target limited spending on technology (see table 7-4 and appendix C). In a recent Department of Education informal survey asking education researchers to list the areas of education research most likely

Table 7.3.–NSF Funding for Educational Technology Research and Development, 1987-89
(In millions of dollars)

NSF program	Fiscal year 1987	1988 (est.)	1989 (est.)
instructional materials development	4.1	7.4	9.0
Applications for advanced technology	5.2	5.6	6.0
Teacher preparation and enhancement	2.5	3.5	4.1
Total technology	11.8	16.5	19.1
Total precollege	60.0	83.0	97.0

[a]Funds from the Teacher Preparation and Enhancement Division that were used for technology are estimates. The amount is difficult to separate from other activities.
[b]Does not include the budget for informal education and major broadcast projects, totaling approximately $7 million in fiscal year 1987.

SOURCE: Office of Technology Assessment, based on data from the National Science Foundation, 1988.

to produce significant breakthroughs and the greatest impact on practice during the next 5 years, "computers in the classroom" tied for third most frequently mentioned. Assistant Secretary for Educational Research and Improvement, Chester Finn, summarized the educators' comments on this breakthrough area:

> The computer will deepen its presence in schools and classrooms as software improves and teachers begin to see it as a powerful tool for getting the job done. The microcomputer offers more information than any teacher can, and it puts that information directly into students' hands, permitting them to interact with it—to manipulate graphs, enact simulations, edit texts. Eventually, a keyboard will be at the fingertips of every student in every class.[42]

[42]Chester Finn, "What Ails Education Research," *Educational Researcher, vol. 27, No.* 1, pp. 7-8, January/February 1988.

Table 7-4.—Department of Education Funding for Educational Technology Research, Development, and Demonstration, 1987-89[a]

	1987		1988		1989	
Office of Educational Research and Improvement (OERI):						
Regional educational laboratories[b]	$1,808,798	(EO)	$ 1,225,926	(EO)	$1,148,456	(EO)
National research and development centers[c]	1,000,000	(EO)	1,000,000	(EO)	Pending	
Educational technology center	2,000,000	(0)	900,000	(0)	1,000,000	(EO)
Field-initiated research grants	62,508	(0)	unknown		unknown	
Programs of national significance:						
Technology awards under science and mathematics, and critical foreign languages discretionary funds competition[d]	530,000	(0)	970,000	(EO)	unknown	
Technology competition	-0-		1,000,000	(EO)	unknown	
Educational television	3,250,000	(0)	2,225,000	(EO)[e]	unknown	
Small Business Innovative Research	1,700,000	(0)	1,700,000	(EO)	1,700,000	(EO)
ERIC Clearinghouse on Educational Technology	288,000	(0)	298,283	(0)	unknown	
National Diffusion Network—technology projects	310,000	(0)	150,000	(EO)	unknown	
Star Schools	—		19,148,000	(A)	-0-	
Special education:						
Technology for special education	4,670,000	(A)	4,790,000	(A)	4,790,000	(R)
Personnel development	2,290,000	(EO)	1,810,000	(EO)	1,270,000	(EO)
Early childhood education	-0-		-o-		300,000	(R)
Vocational education:						
Research center-technology projects	192,091	(EO)	unknown		unknown	
High technology demonstrations	-0-		9,600,000	(EO)	9,600,000	(EO)
Adult education:						
Job Skills Education Program	-o-		128,000	(0)	unknown	

Abbreviations: O: Obligation; EO: Estimated Obligation; A: Appropriation; R: Budget Request

[a]Other programs support technology demonstrations and applications, but there is no information available to document funding related to technology. These include: the Magnet Schools Assistance Act (Title Iii, Education for Economic Security Act—EESA), the Bilingual Education Act (Title VII, EESA, Parts B and C), and three programs authorized under the Higher Education Act (the Fund for improvement of Postsecondary Education, HEA X-A; Leadership in Educational Administration Development, HEA V-C-2; and the Christa McAuliffe Fellowships, HEA V-D-2). Formula funding programs also support technology. These include: Chapter 1, Economic Consolidation and improvement Act—ECIA; Chapter 2 (ECIA); EESA, "Mathematics/Science Program; the Bilingual Education Act (Part A, State and local grants); the Education for the Handicapped Act (State grants); and the Carl D. Perkins Vocational Education Act (Title Ii). With the exception of Chapter 2 block grants, information to document activities related to technology is not available. An estimated 30 percent of appropriations for Chapter 2 block grants is used for technology applications.
[b]Nine regional educational laboratories carry out applied research and development and provide technical assistance within multistate regions. The total annual appropriation is $17 million for 1987, 1988, and 19S9. Funding for educational technology activities comes from OERi grants and other sources. Additional funds for technology were provided to the laboratories through the Rural Education initiative (Education Appropriations Act of 1986) which appropriated $4 million over 2 years and gives a priority to applications of technology. The amounts shown include only Federal funding.
[c]Nineteen centers conduct research on educational topics of national significance over a 3 to 5 year period. The total annual appropriation has been $17.5 million since 19S5. Center awards range from S500,000 to $1.2 million annually. One center has designated responsibility for educational technology R&D, but several others support research projects that have a strong technology component. Some centers support research that may lead to future applications of technology for learning.
[d]Includes critical foreign language projects involving technology, which account for approximately 10 percent of critical foreign language discretionary funds,
[e]Includes $1 million for *Square* One TV, currently under review.

SOURCE: Office of Technology Assessment, based on data from the U.S. Department of Education, *The Fiscal Year 1989 Budget, Summary and Background /formation* (Washington, DC: U.S. Department of Education, February 1988); personai communication and lists of Departments of Education grants and awards, April 1988.

A new technology competition under the Programs of National Significance in the Title II Program for Mathematics, Science, Computer Education, and Critical Foreign Languages will have a funding level of $1 million. There is also a new competition for an Educational Technology Center. However, the RFP calls for less support ($5 million over 5 years, versus $7.7 million from 1983 to 1988 under the current contract) with a much broader research agenda. The new center will be responsible for all curriculum areas, not just mathematics and science, and its mandate will cover not only technology, but also teaching, learning, assessment, and school leadership. Despite the limited budget, interest in the center competition has been very strong. Indeed, the new technology center is perceived as "the only game in town" by the educational technology research community.

No new educational television initiatives are planned, and although the new congressionally mandated Star Schools Program for distance learning projects is authorized at a level of $19.1 million for 1988, no funds are requested in the Department's 1989 budget.

OTA concludes that these efforts fall short of focused, long-term commitments called for by the National Governors' Association, the National Task Force on Educational Technology, and the National School Boards Association.[43]

[43] See National Governors' Association, Center for Policy Research and Analysis, *Time for Results: The Governors' 1991 Report on Education* (Washington, DC: 1986); National Task Force on Educational Technology, op. cit., footnote 35; and National School Boards Association, *A National Imperative: Educating for the 21st Century* (Alexandria, VA: 1988).

PROMISING DIRECTIONS FOR RESEARCH[44]

OTA finds that both recent research results and current demands for change in schools make increased research on technology and education especially promising at this time.[45] Three major factors make this so:

1. **The technology makes possible the testing and trying of new ideas. Some of the best and the brightest scientists and researchers today see education as an important frontier for research because of the potential offered by interactive technologies.[46] Work in psychology, computer science, and artificial intelligence is contributing to understanding coherent the**ories of how people think and learn. These theories can now be tested on powerful computers.[47]
2. **Experimentation at all levels is leading to new uses of technology and demands for increased capabilities. As the installed base of technology** in the schools grows and becomes more powerful, new applications will become possible. Administrators want the technology to be used, and publishers want to exploit markets. As teachers become more sophisticated users of technology, they will demand better products.
3. **Critical educational needs are not being met.** The American public is painfully aware that too many students are dropping out of school, test scores are declining in relation to those of students in other industrial nations, industry is demanding a more skilled and technologically

[44] Much of this discussion comes from Roy D. Pea and Elliot Soloway, "Mechanisms for Facilitating a Vital and Dynamic Education System: Fundamental Roles for Education Science and Technology," OTA contractor report, December 1987.

[45] See Dean Brown et al., "Influences on Development and Innovation in Educational Technology, " OTA contractor report, October 1987. Both this report and Pea and Soloway, ibid., draw heavily on research documents, and personal and written interviews with preeminent researchers in the field. For a complete bibliography, see the contractor reports.

[46] Alan Collins, Bolt, Beranek and Newman, Inc., personal communication, December 1987. For example, Xerox has sponsored, with $5 million in startup funds, an Institute for Research on Learning. One of the goals of the Institute is ". . . to forge a synthesis of technology and learning theory so that the instructional capacity of new tools can be exploited. " From Institute for Research on Learning, op. cit., footnote 24.

[47] "The ability of today's scientists to model the mind on computers was made possible by generations of psychologists who watched and recorded people at work on mental tasks of all sorts, and by the accumulated efforts of artificial intelligence researchers who have been trying to understand the nature of intelligence for over 30 years. Researchers, finding thousands of regularities in the mind's handling mental tasks, are now using the computer to try to assemble those regularities into a larger picture of how the mind performs. " David L. Wheeler, "From Years of Work in Psychology and Computer Science, Scientists Build Theories of Thinking and Learning," *The Chronicle of Higher Education*, Mar. 9, 1988, p. A4.

competent work force, and the number of difficult to teach students (special education students, non-English speaking students, and those from homes where educational support is lacking) is increasing. These problems, coupled with a shortage of teachers in some locations and subject areas, and growing concern over whether we can produce and keep the most talented teachers, all create a demand for change and for a more productive system for schooling.

Research in the cognitive, social, instructional, and computational sciences is changing the understanding of learning and teaching. This different focus is important—education viewed from the learner's perspective, not from the traditional curriculum/subject matter perspective (see box 7-D).

Some of the areas where current research shows promise for educational applications include the development of intelligent tutoring systems, tools which act as intelligence extenders, microworlds for learning, multimedia learning systems, new measures of testing learning, and research on how technology affects teaching and the social structure of schools (see table 7-5).

Intelligent Tutoring Systems

Much of the research on human learning and effective teaching has been channeled into developing artificial intelligence technologies that could simulate human tutoring. There is no question that human tutoring produces the most effective learning. For example, one researcher found that only 11 hours of individual tutoring produced the same level of mastery of the LISP programming language as 43 hours of traditional classroom instruction with supplementary student homework. What is also obvious is the prohibitive expense of one-on-one tutoring. The technological opportunity lies in the potential applications of artificial intelligence in simulating human tutoring.[48]

Cognitive science research is focusing on those aspects of human learning that could be used to develop intelligent tutoring systems. Work supported by the Personnel and Training Research Program at ONR indicates these include:[49]

- understanding how novices and experts solve problems in order to create an "ideal student" model;
- understanding where misconceptions occur when a real student does not perform as the "ideal student" would;

[48] Susan F. Chipman et al., "Personnel and Training Research Program: Cognitive Science at ONR," *Naval Research Reviews*, vol. 38, 1986, p. 14.

[49] Ibid., pp. 15-16.

Box 7-D.--Guided Discovery: Teaching From a Learner's Level of Understanding

The learner-centered approach looks at the learner's prior level of understanding, how preconceptions or misconceptions from earlier formal or informal experience may affect understanding, and where conceptual stumbling blocks exist. Recent research has focused on diagnosing the understanding, preconceptions, and interests a learner brings to formal instruction, so that additional instruction can build upon this base and deal with specific areas of difficulty.

Studies of how students learn science illustrate this approach. Students' preconceptions about concepts such as light, gravity, motion, heat and temperature, weight and density, and other physical phenomena are being examined. The Educational Technology Center at Harvard has identified "targets of difficulty," curricular topics both critical to students' further progress in science and widely recognized as difficult to teach and learn. For example, in the Weight/Density Project, the research group began by analyzing students' beginning conceptions. Although most middle school students do not know what density means, they do have related ideas about "heaviness for size" and what makes some objects sink or float. Most youngsters have one undifferentiated concept for thinking about weight v. density where physicists require two. The distinction physicists make is hard to teach because an object's density, unlike its weight, is not directly observable. The researchers are therefore exploring the use of interactive computer models to help students observe density in a simulated environment they can manipulate and explore. These activities are combined with hands-on activities with objects of different weights, sizes, and densities, along with problems posed by teachers to guide the students as they consider the connections between their experiences with real materials and the computer representations.[1]

[1] Educational Technology #rim, HarvardCraduate~~10{~-cation, "Making Sense of the Future," a position paper on the role of technology in science, mathematics, and computing education, January 19ss, pp. 7-s.

Table 7-5.—Promising Directions for Research: Selected Examples of Intelligent Tutoring Systems, Intelligence Extenders, Complex Microworlds, and Multimedia Learning Environments in K-12 Education

Project[a]	Topic	Grade level	Institution	Funding source
Algebra Workbench	Early algebra instruction using LOGO.	Sixth grade	Lesley College Bolt, Berenak & Newman (BBN)	NSF
Boxer	Programming environments for educators, students, and others	Middle school to adult	University of California, Berkeley (earlier MIT)	NSF
Chips	Tool kit to create graphics intensive programs.	Designers of instructional software	Learning, Research and Development Center (LRDC)	DoD
CMU Tutor	Authoring language to create instructional programs that help diagnose student responses.	Educators and instructional designers	Carnegie-Mellon University (CMU)	NSF
Debuggy	Uses artificial intelligence and cognitive theory to diagnose subtraction errors.	Elementary school	Xerox PARC (earlier BBN)	DoD
Earth Lab	Collaborative learning and experiments in earth science using LANs,	Sixth grade	Bank Street College	NSF
Geometric Supposer	Hypothesis exploration in plane geometry,	Middle school	Harvard University Educational Technology Center	ED
Geometry Tutor	Uses cognitive theory to diagnose student errors in creating geometry proofs,	Tenth grade	CMU	NSF DoD Carnegie Foundation
Green Globs	Uses games and multiple representations to foster understanding of relationship between algebraic functions and graphs,	Middle school	University of Illinois	ED NSF
Heat and Temperatures	Helps students understand heat and temperature through microcomputer lab activities with dynamic visual representations.	Ninth grade	Harvard University, Educational Technology Center	ED
IDEA	Helps students learn to use systematic decision methods to solve problems.	Middle school to adult	New York University	Spencer Foundation
Inquire	Tool programs for active investigation of scientific phenomena.	Middle school	Bank Street College	NSF
INTERMEDIA	Hypermedia environment to create programs linking images, text, and other representations,	Undergraduate	Brown University	Annenberg Apple
Kids Network	Collaborative science experiments using telecommunications networks,	Fourth-sixth grade	Technical Education Resource Centers (TERC) National Geographic Society (NGS)	NSF NGS
LegoLOGO	Children control Lego machines using the LOGO programming language.	Elementary school and up	MIT BBN	DoD NSF
LISP Tutor	Intelligent tutoring system that provides instruction on introductory LISP programming.	High school and up	CMU	DoD
LOGO	Introductory programming language	Elementary school and up	MIT BBN	DoD NSF
Macrocontexts	Uses interactive video technologies to provide functional contexts for science learning.	Middle school	Vanderbilt University	IBM DoD
Microcomputer-based laboratory	Inquiry-oriented science tools that connect data collection hardware to graphing software	Elementary school and up	TERC	NSF ED
Modeling	Computer-based tools that let students build models of systems to learn calculus,	Tenth grade	TERC Lesley College	NSF
PALENQUE	Prototype using digital-video interactive technology that lets user "explore" a Mayan archeological site.	Elementary school	Bank Street College	GE/RCA
Proust	Diagnoses bugs in students' Pascal programs.	Middle school and up	Yale University	DoD
QUEST	A simulation environment for teaching basic electrical theory,	High school	BBN	DoD
Quill	A set of computer-based writing activities that use real documents to teach writing skills.	Elementary school	BBN	ED

(continued on next page)

Table 7-5.—Promising Directions for Research: Selected Examples of intelligent Tutoring Systems, intelligence Extenders, Complex Microworlds, and Multimedia Learning Environments in K-12 Education—Continued

Project[a]	Topic	Grade level	Institution	Funding source
Rat	Microworlds that allow children to interact with representations of everyday objects to learn basic arithmetic concepts.	Elementary school	LRDC	NSF
Reasoning under uncertainty	Introductory statistical reasoning.	High school	BBN	NSF
Sketch	Tutor to help teach graphing of simple algebraic expressions.	Middle school and up	Carnegie-Mellon University	NSF
Smithtown	Discovery world using simulations to teach macroeconomics.	High school and up	LRDC	DoD
SOPHIE	Electronic troubleshooting skills.	High school and up	Xerox PARC (earlier BBN)	DoD
STEAMER	Uses simulation to teach about operation of a steam propulsion power plant.	Vocational training	BBN	DoD
Tinker Tools	Uses game format to help learn basic concepts in Newtonian mechanics (mass, energy, and velocity).	Sixth grade	BBN	NSF
Vivarium	Computer-based models for ecology.	Elementary	MIT Los Angeles elementary school	Apple
Voyage of the Mimi	Uses multimedia materials for informal and classroom-based learning of mathematics and science.	Fourth grade and up	Bank Street College	ED NSF CBS Sony
West	Employs the coaching paradigm and a computer game format to teach basic arithmetic skills.	Elementary	BBN	DoD
Word Learning	System that helps children learn the meaning of words by providing different characterizations of the meaning of words in a passage.	Elementary school and up	Princeton University	DoD Spencer Foundation
Word Problems	Prototype using multiple representations to help students learn about reasoning with intensive quantities.	Elementary	Harvard University Educational Technology Center	ED

Abbreviations: NSF = National Science Foundation, DoD = U.S. Department of Defense, ED = U.S. Department of Education, GE = General Electric, MIT = Massachusetts Institute of Technology, LANs = local area networks

[a]Projects listed represent th. broad range of innovative applications of technology to probiems central to cognitive, social, and instructional sciences Of education, particularly in the area of K-12 education. This is by no means an exhaustive list

SOURCE: Office of Technology Assessment, 1988.

- defining the strategies of effective human tutors (knowing how to present information, what problems to present next, when to interrupt, when to explain);
- developing representations of real systems which learners can manipulate and explore, to try out hypotheses and "what if?" kinds of thinking. (What if I change this variable? What if it breaks down? What if I want to make another like it?)
- trying out various student-tutor interfaces to determine how easily the student can get at the knowledge contained in the tutor's ideal student model;[50]
- showing various graphic means which can illustrate ways of solving problems; and
- studying how instruction can be adapted to limitations in the student's attention span or ability to absorb information.

An example of an intelligent tutoring system which incorporates at least limited capabilities in all these areas is the Geometry Tutor developed at Carnegie-Mellon University. ONR funding for early research, later supplemented by NSF support for development and the Carnegie Foundation support for testing in the schools, brought this concept from

[50]"The interface between the user and the computer may be the last frontier in computer design." James D. Foley, "Interfaces for Advanced Computing," *Scientific American*, October 1987. Examples of interfaces are touch-sensitive, plasma-panel screens, the "mouse" pointing device, the chorded key set, and on-screen windows; icons, menus, browsers, overlapping windows, and the bitmapped display; eyetracking; and the Dataglove. (See Brown et al., op. cit., footnote 45, app. III.)

basic research to classroom trials in the Pittsburgh public schools. Other intelligent tutors are being supported by NSF for Pascal programming and an intelligent tutor for high school algebra.

Intelligence Extenders

There is a major class of tools for learning and problem solving, variously described as "cognitive technologies, " "intelligence extenders, " "cognitive workbenches" or "mental prostheses. " These software tools enhance the utility of computers by their capacity to quickly and accurately manipulate symbols, including pictures, text, diagrams, numbers, and sound. They can be used in various combinations as needed.

For example, text editors and graphics tools in word processors enable the writer to manipulate language with new ease and grace. Using these tools, writers find that revisions come more easily, thoughts can be reformatted, rearranged, and given new expressive shapes previously not possible in the world of erasures and cut-and-paste editing. These adjustments and revisions in writing are techniques that are associated with expert performance among writers, yet even the most inexperienced of students can benefit from the assistance these intelligence extenders provide to help them write more fluently.

As these tools now approach second-generation or integrated tool levels, they can be customized by teachers and publishers for different curricular areas and topics. Like dBase III, a powerful general tool for various database applications, or *Lotus 1-2-3,* which offers multiple spreadsheets and modeling applications for business, comparably powerful "engines" for education could spawn customized development and applications by the teacher for classroom use. *HyperCard,* the latest associative tool, allows the

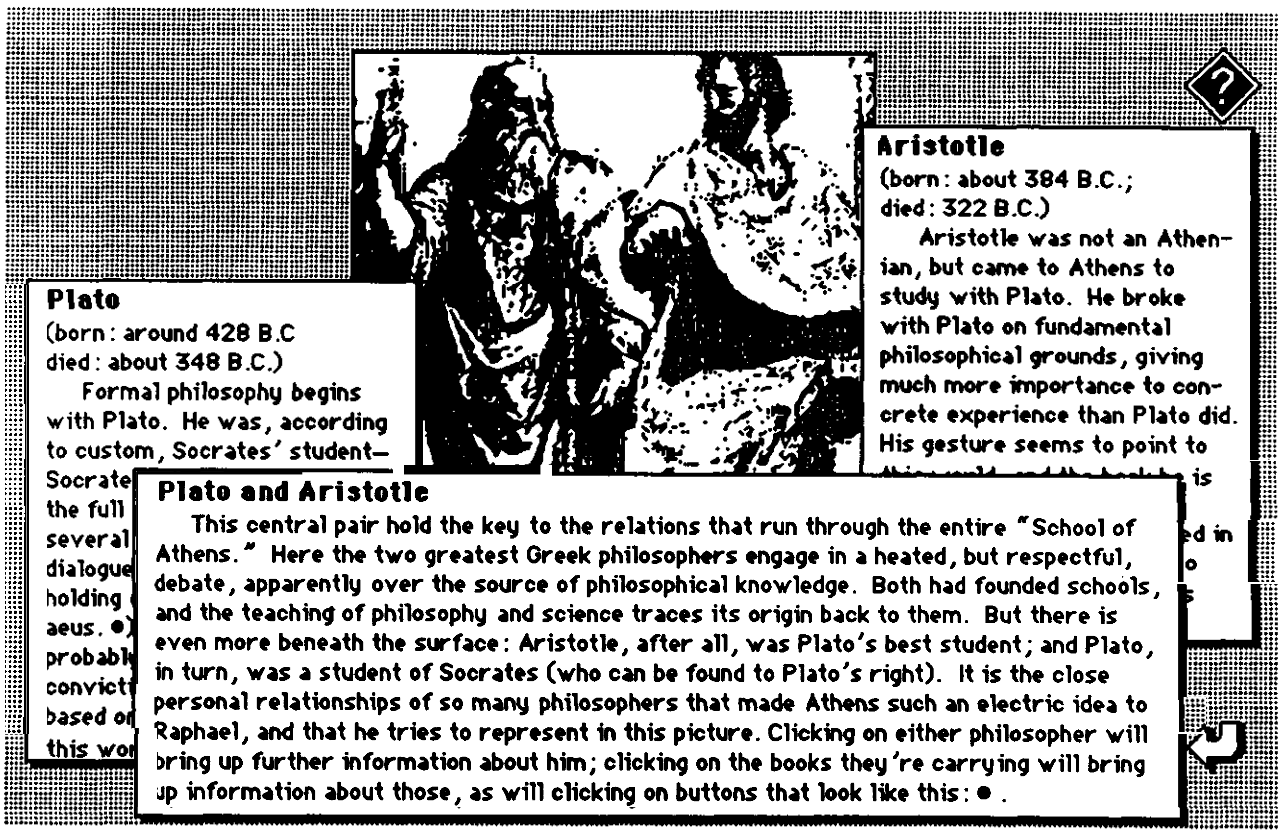


Photo* credit: *John Camp, Wayne State University

HyperCard software lets teachers create their own instructional software, linking topics as desired. In this "School of Athens" *HyperCard* stack, students "click" on a figure to bring up more information about the philosopher or on the question mark for general information or help.

user to create and link together "cards" of intermixed text, graphics, videodisc images, and sound. This software tool also includes a powerful, but simple, programming language. *HyperCard's* lineage **can be** traced back to Memex,[51] the forerunner of today's "hypertext," "idea processing," and outline processing systems. Much of the work creating tool **"en**gines" has been taking place at the university level **over** the past 5 years, **as** in Project Andrew at Carnegie-Mellon University, Project Athena at the Massachusetts Institute of Technology, and Brown University's IRIS Project.

Among the **most** promising **uses** of technology tools are those for exceptional students. Innovative projects include braille word processors for the blind, specially designed materials for teaching English syntactic structure to improve the reading and writing skills of the deaf, and synthesized speech generated by touching graphics tablets, enabling students with little **or no** capacity for **oral** language to communicate.

Increasingly Complex Microworlds

In increasingly complex microworlds a computer representation of a situation **or** environment **ena**bles the student to learn about the content area by exploring the representation, and to practice a skill in progressively more complex computer-generated simulated environments.

W M Mo

Photo credit: Adaptive Communications Systems, Inc.

One of the most promising areas of research is technology to serve exceptional students. Typing his words into this computer generates a speaking voice for this young man.

Microworlds are valuable learning tools because students **can** learn by doing, by acting **on** the microworld rather than merely observing phenomena. They **can** be very powerful stimuli for understanding how things work. Some microworld systems let students build or program their **own** worlds, allowing them to explore the properties of the system and their relationships by examining the consequences of changes to these properties.

For example, in the LegoLOGO project, students write LOGO programs to control Lego machines, connecting programming and real-world objects such as gears, levers, and sensors, to introduce key concepts in physics, engineering, and robotics through an experimental approach. In microcomputer-based laboratories students learn science by doing it. Alternatively, imaginary microworlds **can also be con**structed (e.g., non-Newtonian universes) which offer **new** opportunities to bring to life things that students could never see **or** imagine without the technologies. The microworld **can offer novel op**portunities going beyond the limits of the **real** world, allowing the learner to delve into created worlds of fantasy and exploration. Examples of microworld R&D include systems for early physics learning (Dynaturtle; Thinker Tools); systems for exploring electrical circuit behavior (SOPHIE; QUEST); economic systems (Smithtown); physical systems (STEAMER); and ecosystems (The Vivarium Project).

Multimedia Learning Environments

Print remains the medium of instruction in schools today, just as it was a century ago. Video, audio, graphics and other representation of information are used far less, despite the fact that they **are** highly motivating and effective for learning, and most often the sources of the learning that takes place outside the schoolroom.

Researchers **are** studying ways learners process information presented in nontext media, and how various symbols (pictures, diagrams, graphs, flowcharts, etc.) affect understanding.[52] As discussed in

[52] See Mary Alice White, *What Curriculum for the Information Age* (Hillsdale, NJ: Lawrence Erlbaum Associates, 1987).

chapter 8, new developments make it possible to combine video, audio, and graphics to provide information in varying formats that the teacher can control and access quickly. Object-oriented graphics editors, digital scanners for photos and video frames, and animation tools are available for computers at reasonably low cost, and are being used in learning technology development work in the research laboratory.

A future scenario illustrates how these multimedia tools could be used in the classroom. Picture the elementary school teacher discussing earth science and plate tectonics with the class. Using the computer as a multimedia control device, the teacher pulls up for computer projection dramatic online video clips of volcanoes. Students use an interactive microworld to examine how continental drift operates, and slides of fossil remains from different continents show how now-dispersed land masses were once connected. One student has the idea of photographing local geological strata, another brings in a home video of television footage on volcanoes he thinks might be relevant, another tapes the sound of storms to produce an audio soundtrack. When they return the next day these auditory and visual images are scanned into the classroom archives for other students to use. Electronic messages flow between students and from teachers to students when difficulties arise or to share new ways of thinking about what is being learned. Students work at multimedia composition work stations, revealing what they have learned by constructing and revising their own reports about plate tectonics from these and other materials they have found and pulled together.

New Measures of Assessing Learning

Tests play a role in the learning process by telling students what in the curriculum is important.

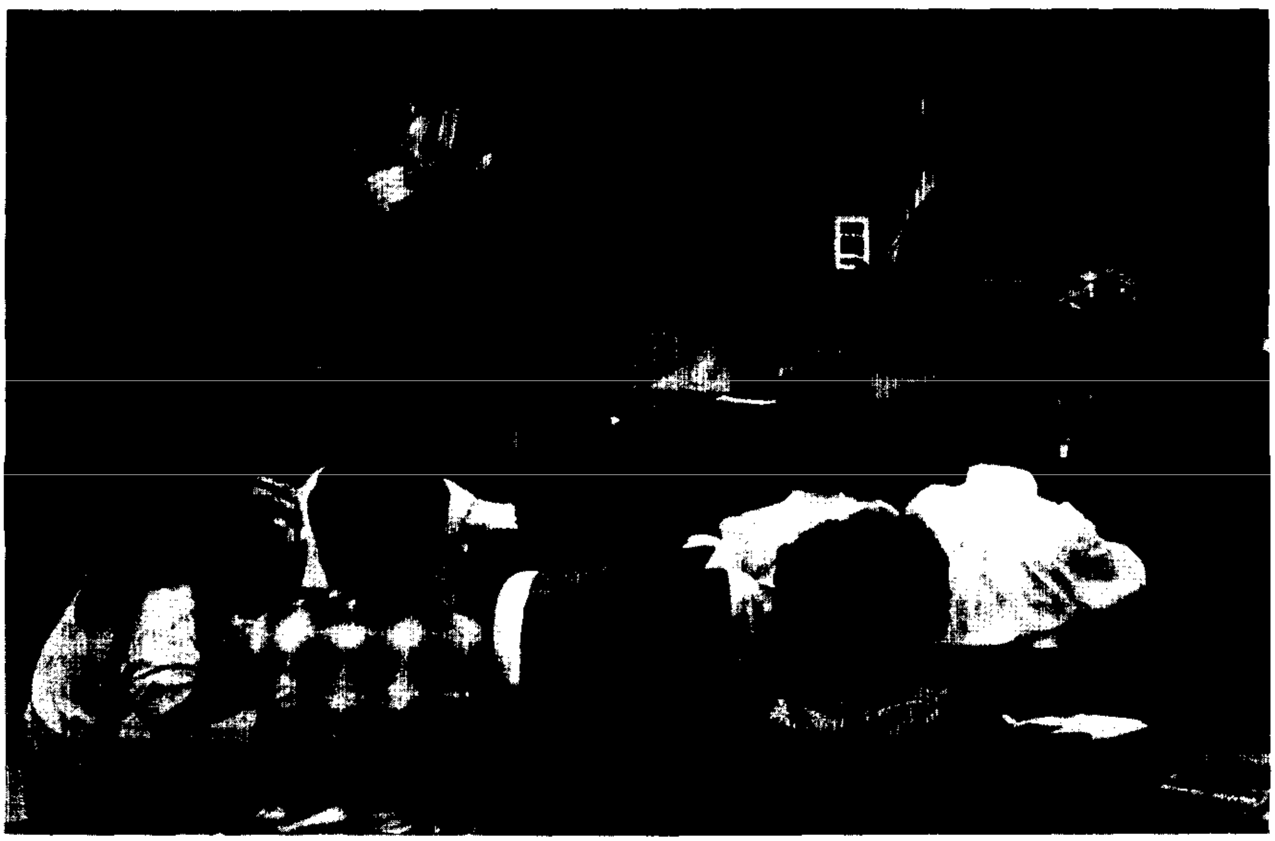


Photo credit: Optical Data Corp.

New developments with interactive multimedia make it possible to combine video, audio, and graphics to provide information in varying formats the teacher can control and access quickly.

If, for example, testing is confined to memorizable end results, teachers will teach facts and students will memorize them to score well on tests, ignoring the more sophisticated levels of understanding and reasoning which education aims to foster. At present, very little school testing is directed toward measuring students' conceptual understanding. Researchers suggest the need to devise new assessment strategies that analyze the attainment of nontrivial skills, with particular attention to "complex thinking skills" such as the ability to generalize appropriately, to invent analogies and use them critically, to take problems apart into interacting parts, to effectively manage and deal with complexity, to lay out a procedure as a sequence of approximations which converge to a solution, and to analyze a situation from a viewpoint other than one's own.

Photo credit: *Kalamazoo Area Mathematics Center*

New kinds of problem solving are made possible using the real-life tools of mathematics, a graphing calculator and computer.

Another important feature of testing should be the ability to diagnose the student's present level of conceptual understanding, taking into account the preconceptions or misconceptions he or she brings to the learning situation. These prior beliefs may frustrate traditional instruction and need to be identified so that the teacher can address them appropriately. Research is needed to develop instruments for measuring deep conceptual understanding and diagnosing prior understandings.

An additional approach to assessment calls upon learners to evaluate themselves as they are learning (e.g., testing comprehension in reading) and to work strategically to overcome difficulties as they are experienced. Here, too, today's tests are inadequate for self-assessment of understanding or skills.

Research on How Technology Affects Teaching and the Social Structure of Schooling

A last but important area of educational research focuses on the social context in which learning takes place. For example, teachers can make a difference by creating and maintaining an open environment in which making mistakes is an accepted part of the learning process, and in which different approaches to problems are welcomed as opportunities for group learning. Such an environment appears to influence whether a student treats work on a problem as an opportunity for learning or as an occasion for failure and low self-image. And a teacher's negative expectations for a student's performance often become self-fulfilling. The computer, with its immediate and private response to the student's input, can be one antidote.

Social relations with peers in the classroom can also be harnessed to contribute to cognitive growth. Numerous studies indicate that group discussions of strategies for solving a problem can be important vehicles for learning, by making explicit to each member the merits of different approaches and viewpoints.

All the ways technology can enhance what students learn, how learning is measured and how the

curriculum can be reconfigured will have major implications for the teacher's role (see chapter 5). Without new training efforts to teach with, not about, technology, the innovations discussed above will make little impact on education. As one researcher said:

> The problem with education now is not what students are capable of, but what teachers are capable of, given their previous education. The main problem of educational research and development is to educate teachers to teach to students' conceptual understanding, and to teach them to diagnose students' alternative frameworks for thinking about what is being taught.[53]

Few experts see the technology replacing the teacher. Some believe that this is what intelligent tutors are being designed to do, but most think only a small part of formal education can be mechanized in that fashion. instead, most experts see ways in which the computer can be used to revitalize the teaching profession. For example, the computer could provide better ways for teachers to see incremental changes in students' understanding of concepts to diagnose areas of special difficulty. This will improve teachers' abilities to teach based on an understanding of the student's particular stumbling blocks.

Computers could also help make the teacher's role more one of "coach" than delivery agent of learning. Such tools as microworlds, word processors, and database programs enable students to work individually or in small groups focusing on problem solving activities. In this mode, peer learning is facilitated, while the teacher guides the students in a process of discovery learning. (See box 7-D.) Some see this as an even more intellectually challenging role for teachers than that required in the lecturer/test-deliverer teaching model common today. Computers could also promote more effective learning for the teachers themselves as they use technology in preservice, inservice, and networking activities.

Technologies may have a special role to play in research on the "Microsystems" of schooling, which deal with the social organization of instruction and curriculum content. For example, networking technologies could fundamentally change the communication systems of classrooms, connecting teachers and students to a nearly limitless number of learning and teaching resources, including information databases and teachers, specialists, and others students, as close as the next seat and as far as across the ocean.

[53] Susan Carey, "Cognitive Science and Science Education," *American* Psychologist, vol. 41, 1986, pp. 1123-1130.

BARRIERS TO IMPLEMENTATION

A number of barriers stand in the way of moving from research to application in the classroom. Many educators fear that without major restructuring of schools, such as allowing teachers much more flexibility in controlling the curriculum, opening up the time-in-grade system to that of student movement based on individual progress in meeting instructional goals, and other improvements to the educational system, no significant changes will or can be made, with or without technology R&D.[54]

Problems of funding, leadership, and strategic planning have been highlighted in previous sections of this chapter, while others are discussed in detail in other sections of this report (see chapter 5 on the teacher's role and chapter 6 on software). There are additional barriers:

- The lack of consistent stable funding means that ideas rarely can be sustained through experimental and applied development with appropriate classroom testing and evaluation. Prototype development is not enough to bring the results of basic research into classrooms.
- The hardware necessary to conduct sophisticated artificial intelligence research is extremely expensive. Small grants or contracts to researchers will not suffice.
- The installed base of technologies in the schools today is not powerful enough to run some of

[54] "Technology can never replace teachers. But the lack of new technologies in our schools—or the use of technology as if it were no more than a modern blackboard or drill sheet—is certainly squelching real teaching and learning. We've always talked about getting out of the rut of teaching as information dispensing and overcoming a 'one best system' of student learning that denies individual differences and needs, despite all our rhetoric to the contrary. Well, in technology we have the opportunity. The question is, will we take it and what will we do with it?" Al Shanker, president, American Federation of Teachers, personal communication, Mar. 22, 1988.

the more sophisticated software applications produced by advanced research. In order to experiment with advanced applications, research projects need to be allied with schools and make the necessary advanced hardware systems available to them.[55]

- There is need for long-term comprehensive evaluations of different approaches, including those utilizing technology. Schools are justifiably cautious about using real students as "guinea pigs" for radical approaches without some track record of success.
- There is a shortage of research scientists to do this kind of interdisciplinary research. Currently we have not infused ". . . enough sense of national emergency into the work to attract them away from other attractive projects. "[56]
- Differing design features in the technology bedevil the education R&D community and practitioners. Many argue for standards in interface design so research can translate across machines, to ensure compatibility, to reduce learning time for users, and to make finding and storing data easy for even the youngest students.

[55]For example, in order to *test* the *Geometry* ***Tutor*** in schools, the researchers at Carnegie-Mellon University had to loan computers to the test sites in the Pittsburgh schools. The Geometry Tutor's high-level software required more powerful machines than the schools had. Although the final version has been adapted to run on a Macintosh, even these are rare in high schools at this time.

[56]George Miller, Princeton University, personal communication, December 1987.

POLICY OPTIONS

The Federal Government has a clear responsibility in supporting R&D for educational technology. Only **the Federal Government can marshal the resources to conduct the R&D necessary for the development of high quality teaching tools and materials, for creating and testing technological systems, and for demonstrating and evaluating the applications of technology to a wide range of educational problems.** Several options are possible.

Option 1: Take No Action

Under this option, current levels of funding and organizations for educational technology R&D in Federal agencies would be maintained. Some suggest that the existing Federal organization for R&D is appropriate and has served to support important research that eventually makes an impact on classroom teaching and learning. Under this option, funding for technology would probably reflect Federal budget restrictions. The private sector could be encouraged to provide greater support for educational technology R&D.

This approach would be appropriate if we wish to maintain the status quo. Some educators feel that technology is overrated and costly. They contend that educational priorities must first address measures that upgrade the teaching profession and restructure the organization of schooling. However, these reforms are also very costly and carry no guarantee of improved student learning. The promise offered by new technologies for improving learning suggest that, although technology has significant costs, it could be as promising an investment opportunity as any other major school reform proposals.

Furthermore, maintaining the current level of effort for Federal R&D on technology could result in missed opportunities for significant educational change. Existing problems in Federal support for R&D (gaps in subject areas, poor coordination, inability to support major, long-term research projects, shortages of research facilities and manpower, and lack of classroom testing and evaluation of products and procedures) would be perpetuated. Finally, adopting a policy of no change would send a signal to the education and research communities that technology is not a priority area for educational improvement.

Option 2: Increase Resources in Existing Programs

Congress could direct Federal agencies to provide a greater focus on educational technology R&D and increase funds for the R&D budgets of existing technology programs. As shown in tables 7-3 and 7-4 and in appendix C, there are many programs that could do more if resources were increased and congressional intent were made clear. Congress could direct the Department of Education and NSF to increase funding for R&D in these programs, while also increasing funding for the 6.1 research components in DoD which contribute to this effort.

Under this approach, agencies could plan to target greater amounts of money over the next 5 to 10 years to R&D in technology. Staged growth would allow for support to greater numbers of graduate researchers whose growing expertise could seed further research. Funds could be targeted at several levels: to individual researchers, to existing centers such as NSF and the Department of Education's Technology Center, as well as other laboratories and centers. These grants and contracts could require school system collaboration, and might require contributions from the private sector to leverage Federal dollars.

Larger levels of support could make possible an integrated approach to curriculum development in areas of special need which require stable, long-term support. For example, a recent NSF planning grant for a pilot demonstration on the use of advanced technologies concluded that ". . . in the absence of private sector investment in the computer curriculums necessary . . . the Federal Government should subsidize their development at an estimated cost of $20 million for eight secondary-school science and mathematics courses."[57] This same report suggested that a front--end investment of between $1 million and $3 million per course is necessary to begin such large scale efforts. Similar levels of effort would be required in other areas of the curriculum.

However, increased funding is not likely to resolve other problems of research coordination and long-term implementation.

Option 3: Facilitate R&D Transfer and Applications

Congress could direct the Federal agencies to adopt policies which would enhance R&D transfer within and across agencies, and from laboratories into schools. Activities could include:

Interagency funding of projects. This is one mechanism that could increase coordination and support larger efforts.[58] However, past experience with this approach points to difficulties of securing interagency agreements on objectives, procedures for awards, and requirements for reports or contracted products. Congress has sometimes viewed joint funding as duplicative.

Collaboration among programs. Support from a variety of discretionary or operating funds within agencies can bring together Federal program managers, in-house researchers, and external grant and contract recipients to present findings on work in progress. Meetings on topics of mutual interest could provide cross-fertilization of research ideas. With better awareness of work in progress, Federal officials could target discretionary and operating funds to developments that seem most promising, as well as to areas where gaps exist.

Coordinating activities and meetings of this scale requires resources—staff time and funds for travel and per diem. While these are not large expenditures, many grants today, especially in the Department of Education, do not include travel funds for researchers, nor have agency staff been encouraged to travel to professional meetings.

Electronic networks for research and dissemination. The history of ARPANET and the recent establishment of research networks in NSF demonstrate the important resource these provide for communication and collaboration among funders, researchers, school practitioners, and policy makers.

[57] Arthur S. Melmed and Robert A. Burnham, "New Information Technology Directions for American Education," Report for the National Science Foundation, December 1987.

[58] The Departments of Education, Labor, and Defense have supported an innovative technology, transfer program involving the military's Job Skills Education Program (JSEP). Representatives from each agency met for nearly 2 years as an Interagency Working Group on Adult Literacy to accomplish this transfer. With joint funding from the Department of Labor ($500,000) and the Department of Education ($128,000), the military's computer-based job skills educational materials are being converted for use in functional literacy programs in the civilian sector (students in high school and adults in other programs). Florida State University and Ford Aerospace Corp. will transfer the JSEP materials for use on IBM compatible hardware and develop manuals for using the system. Staff from the Army Research Institute who had worked directly on the JSEP program coordinated the details of making this technology' transfer feasible. The Department of Labor is funding three demonstration sites in California, Delaware, and Indiana, where State vocational education and Job Training Partnership Act personnel are playing a key role. New York State is supporting two demonstration sites as well. Karl Haigler, director, Adult Literacy Initiative, U.S. Department of Education, personal communication, June 1988.

Nevertheless, various research communities have limited access to one another, with the education community the most infrequent user. Congress may want to study how national networks can better serve the needs of the education and research community, especially as rising costs discourage network usage.

Congressional oversight. Congress could request an annual or biannual report that: a) reviews the activities of all Federal agencies involved in educational technology, b) identifies opportunities to transfer technology from one type of activity to another, and c) recommends steps to be taken for further research or in transfer activities. Requests for periodic reports to Congress are not unprecedented, particularly in areas of rapid development and high national interest. Periodic reports could motivate agencies to collect and analyze information in a more systematic fashion.

Agencies may consider this an extra reporting burden. Some agencies are organizing information on technology funding and project scope for their own purposes (e.g., DoD), but considerable resources are required to make information databases useful. Assembling an annual report would require expenditures to provide trained personnel to coordinate the assessment and the computer support for developing and maintaining databases.

Option 4: New Initiatives

The magnitude of the problems facing education, increasing demands for a better trained populace to meet international economic competition, and promising applications of technology for learning argue for a different approach. More than band-aids on the existing system may be required; instead, some suggest consideration of totally new initiatives that would provide a national focus on technology and educational improvement. That technology can improve the productivity of the workplace is no longer in doubt. Whether it can offer comparable improvements to education needs to be tested. Major commitments to R&D could explore classroom applications and changes to make learning more productive: allowing teachers time to spend with individual students, coaching and tutoring them; and tailoring instruction to each student's level of understanding, learning speed, and learning style. To find out whether these goals could be realized requires a major investment in R&D. Perhaps it is time for education to invest the same fraction of gross expenditures on research as does the average privately owned business in the United States. If that were the case, about $9 billion a year would be spent for education research. This is 60 to 90 times more than the present allocation.[59]

Options incorporating this level of focus and investment include support for centers for interactive technology and education, major long-term demonstrations of technology in schools, and funding a national "education futures" project, or a combination of the above.

Centers for interactive technology and education. These centers would conduct research, development, demonstration, evaluation, and dissemination of educational technology projects.[60] They would be tied closely to schools and involve teachers in research. The work could be modeled on the Department of Education's Educational Technology Center; the differences would be the scale of effort and funding, the interdisciplinary research focus, and the long-term commitment. Such centers would have several attractive characteristics. They would encourage the coordination of technology use in teaching and learning. They would integrate all stages of R&D, from science to classroom, in one setting, providing opportunities for technology transfer among the center and schools, Federal laboratories, private industry researchers, and university research. They would stabilize the R&D effort, making it possible to attract and keep the best personnel who could see projects through to final evaluation and dissemination. There would be economies of scale, making it possible to support costly advanced hardware and bring together a variety of people from various specialities, enriching the research mix. Finally, centers would provide training opportunities for teachers and graduate students, enlarging and enriching the manpower pool for educational technology R&D.

But there are drawbacks. Such centers are expensive. A new major funding commitment (from $5 to $10 million per year) in a time of budget deficits

[59]See Office of Technology Assessment, op. cit., footnote 1, p. 49.

[60]For a fuller discussion and description of centers for interactive technology and education, see Pea and Soloway, op. cit., footnote 44.

may be unrealistic. Centers could duplicate current efforts. What would be their relationship with existing Federal centers and their research in this area? Would important work in progress now lose support to continue? Would independent researchers still be supported for smaller efforts not tied to the work of the centers? Would new centers strip existing university research centers of their best people, given the shortage of highly skilled personnel? Finally, the long lead time for research applications to reach fruition could be politically unpopular and jeopardize future funding. Experts estimate that many products in the R&D pipeline now could take a decade or more before they can be expected to make a significant impact on the classroom.

Long-term demonstrations of technology. The scale and scope of these demonstration schools would be much larger than current demonstrations that typically focus on one technology product or process with just one class or a small group of students in a school. Technology demonstration schools could be representative of the student population nationwide and involve all the school resources (teachers, researchers, equipment, curriculum, parents, community support) for applying technology in school activities. Demonstration sites would make it possible to evaluate the educational effects of a technology-rich school environment.

The costs of setting up and sustaining demonstration schools would be large, requiring the Federal Government to reimburse States and local districts for the extra required resources. States and districts sponsoring demonstration sites would have to agree to relax standard requirements for curriculum, teacher staffing and salaries, and organizational and administrative restraints, in order to provide a site allowing for experimentation. And not all schools would benefit equally at first, raising concerns about equity and the choice of sites.

A "national education futures initiative" for research, development, and demonstration in educational technology.[61] This option, on the order of $1 billion per year for 10 years, could include the initiatives suggested above, as well as support all levels of research, development, and demonstration; teacher training; software development; longitudinal and comparative evaluations; and dissemination. Congress could include a sunset provision, using the year 2000 as an endpoint, a period in which the Federal effort would make enough of an impact on education to create significant change. In addition to focusing the Nation's attention on technological solutions, an initiative of this order could also strengthen the hardware, software, and telecommunications industries, which have become important industries for U.S. economic competitiveness. Many educators have suggested that the magnitude of U.S. educational problems, and the Nation's decreased economic competitiveness, require an initiative on this order.

This effort would require the establishment of a coordinating body—possibly a new institution made up of staff from existing Federal agencies, university laboratories, school personnel, and members of the private sector.[62] It would draw resources, both personnel and financial, from other sectors as well as from other approaches to educational improvement. Other social programs might suffer funding cuts to support an educational buildup of this order. Finally, this level of Federal activity in education could prove politically difficult if it led to the development of national curricula or national educational standards, or if the public became impatient and did not detect significant educational improvements after the first few years of funding.

Option 5: Support International Cooperation

The European community, Canada, Australia, Japan, Israel, the Soviet Union, and other nations are embarking on major efforts to use interactive technologies to improve instruction. These efforts share common concerns, experiences, and outcomes with U.S. educational technology activities, despite vary-

[61] Models for this level of effort include the Manhattan Project in atomic energy and the Apollo Mission to put a man on the moon. Both these programs sprang from a sense of national emergency and concentrated human, financial, and technological resources in a clearly articulated strategic plan of action. A national education futures initiative would not have the simply defined technical goal that characterized Manhattan and Apollo, but would focus national resources and provide momentum and commitment.

[62] In hearings on Federal educational research, the British "quango" was suggested as a model for a public/private coordinating agency. See Major R. Owens, chairman, Subcommittee on Select Education, House Committee on Education and Labor, "Opening Statement," Oversight Hearings on the Office of Educational Research and Improvement, Apr. 20, 1988.

ing educational goals and cultural differences. There is much we can learn from one another.

As information technologies are used to link students and classrooms all over the world, it may be appropriate to support larger efforts for international cooperation. Congress may wish to consider international cooperative efforts such as sponsorship of conferences,[63] exchange of researchers, and joint funding of projects. Models for this occur in other areas of science, but little has been done to date for cooperative educational technology projects. As the Chairman of the 1987 Organisation for Economic Development and Cooperation conference stated:

> Some educators would advise caution and warn against the possibility of creating too great expectations. . . . Such views are praiseworthy but we should not be daunted by the magnitude of the task. The application of information technology to education requires new and imaginative approaches. The potential return is very high indeed.[64]

[63] The Center for Educational Research and Innovation of the Organisation for Economic Cooperation and Development has sponsored international conferences on education and information technology. See Organisation for Economic Cooperation and Development, *New Information Technologies: A Challenge for Education* (Paris, France: 1986); and Organisation for Economic Cooperation and Development, *Information Technologies and Basic Learning (Paris, France:* 1987).

[64] Quote from Denis Healy of Ireland, *Information Technologies and Basic Learning,* sponsored by the Center for Educational Research and Innovation (Paris, France: Organisation for Economic Cooperation and Development, 1987), p. 13.

On the other hand, some would argue that the resources available for enhancing educational technology in this country are already scarce. To attempt to support international efforts might put too great a strain on our system. Others suggest that the centralized educational systems of other industrial nations, or the special problems of developing nations, would make it hard to generalize research results into useful programs for this country. More study is needed to identify the U.S. position with regard to other countries and to consider ways in which international efforts could proceed.

Conclusions

OTA concludes that increased coordinated support for R&D in educational technology is necessary. Significant improvements in education can be made if sustained support is made available for development of new tools for teaching and learning. The private sector, while a contributor to this effort, does not have the primary responsibility or appropriate vision for making this a priority. States and localities do not have the capacity. The magnitude of the challenge facing education, allied with the potential offered by new interactive learning technologies, requires that the Federal Government accept this responsibility and opportunity for leadership.

Chapter 8

Technology and the Future of Classroom Instruction

Photo credit: Education Week

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Technology and the Future of Classroom Instruction

. . . the computer is an innovation of more than ordinary magnitude, a one-in-several-centuries innovation and not a one-in-a-century innovation or a one-in-ten years innovation or one of those instant revolutions that are announced every day in the papers or on television. . . .
Herbert A. Simon[1]

What we need to do, then, is to educate as though this technological revolution is what it really is—the third learning revolution—the most important change in learning since the 16th century.
Mary Alice White[2]

INTRODUCTION

The current wave of educational technology, which began roughly in 1981, when schools first began acquiring computers in large numbers, is a good news, bad news, good news story. **The good news is that schools showed a remarkable willingness to invite computer technologies into the classroom, and to see how these interactive cognitive tools could be applied in a setting devoted in large part to training young minds to think.** American schools are often criticized for their slowness to change,; for their lag in adapting to modern times. Yet their eager embrace of computer technology may signify a break with the past: despite the constraints of local budgets and the exigencies of distributional equity,[4] the United States has been among the world's leaders in providing public school children access to new technologies. The fact that U.S. schools were willing to meet the challenge of the new information world and to attempt to integrate a nascent tool into their already dense curricula is perhaps more important than the limited "proof' of educational improvements.

The bad news, however, must be reported too: even this remarkable achievement in the schools pales in comparison with the rate and magnitude of entry into the age of information experienced by business, the military, higher education, and medicine. A handful of classrooms have one computer for each child and another one for the child to use at home (see box 8-A). But in general, classrooms today resemble their ancestors of 50 and 100 years ago much more closely than do today's assembly plants, scientific laboratories, and operating rooms. A number of information technologists point out that if business organizations today evolved at the same rate as the schools, they would still be using quill pens instead of electronic word processors. It might be argued that the complex goals of education are not necessarily advanced by application of new electronic gadgets, and certainly not in the same obvious way that accounting tasks have been simplified with the electronic spreadsheet or file management has been streamlined with database systems. Nevertheless, the chasm in technological sophistication between our schools and the environment in which students will work gives pause.

But there is more good news: under the right conditions there is reason to hope that the new technologies will continue to spur major school

[1] Herbert A. Simon, "The Computer Age, " *Computers in Education: Realizing the Potential*, Report of a Research Conference (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement, August 1983), p. 37.

[2] Mary Alice White (cd.), "Information and Imagery Education," *What Curriculum for the Information Age?* (Hillsdale, NJ: Lawrence Erlbaum Associates, 1987), p. 63.

[3] See, for example, David K. Cohen, "Educational Technology and School Organization, " paper prepared for the Conference on Technology in Education in 2020: Thinking About the Not-Distant Future, Harvard University Educational Technology Center, Oct. 15-17, 1986. This conference was supported in part by OTA. This paper and others presented at the conference will be published in Raymond S. Nickerson and Philip P. Zodhiates (eds.), *Technology' in Education in 2000* (Hilldale, NJ: Lawrence Erlbaum Associates, in press).

[4] See James Guthrie, "Campaign '88 and Education: A Primer for Presidential Candidates," *Phi Delta Kappan*, vol. 69, No. 7, March 1988, pp. 514-519.

Box 8-A.—Apple Classroom of Tomorrow

In the Apple Classroom of Tomorrow (ACOT), each student and each teacher has a personal computer at school and another one at home. These computer-saturated classrooms now reach grade 2 and 3 children in Cupertino, an affluent community in California's Silicon Valley; grade 5 and 6 students at an inner city school in Memphis; a grade 4 suburban school class in Nashville; grade 9 and 10 classes in downtown Columbus, Ohio; and grade 5 and 6 students in Blue Earth, a rural Minnesota community.

ACOT attracts much attention, and ACOT schools are regularly visited by television and newspaper reporters, community members, parents, and other educators. Perhaps the positive effects can be attributed to this special attention, but teachers note that the children adapt rapidly, with little difference between their performance in this "fish bowl" environment and a normal one.

ACOT teachers have common experiences, in spite of the many different conditions, personalities, attitudes, and levels of computer expertise. In particular, many teachers report they are exhausted from the increased stress of learning new skills, evaluating software, and inventing ways of incorporating the computer into the curriculum. But they are also renewed by the effect of their travails on students. They have found a new source of pride in and enthusiasm for their profession.

For some students, having a computer at home has elevated their interest in homework; others derive extra esteem from becoming the family computer expert; and many students watch less television. In Memphis, the children have a modem at home and access the ACOT bulletin board. For children who are home bound with family obligations, such as caring for siblings, and for those who are shy and relatively uncommunicative in person, being able to use the computer as an electronic mailbox inspires a surprising flood of communication.

A computer on every desk creates an entirely different educational environment from a room with a few machines at the back of the class or a school laboratory attended only once or twice a week: computer use in these special places averages about 50 percent of the school day. Where the computers are networked, software is centralized and computer activity is more strictly controlled than in classrooms where the computers stand alone and students load their individual collection of software diskettes. There are advantages and disadvantages in each system. A networked system can ensure that students are attending to the same program, and can facilitate recordkeeping and management. Separate computers reduce teacher control over the activity of each student; but students seem to have greater confidence and mastery of the technology and to branch out on their own to explore different software when they have completed an assigned task.

Cupertino ACOT classrooms incorporate computer use into many areas of the curriculum. The teachers often gather the children around only one computer to demonstrate new software or to engage them in group activity. At other times two or three students work together. They also work alone on keyboarding, writing, and mathematics. In Columbus, the ACOT high school classrooms are networked. Teachers design assignments and download them to the students in the class. They manage records easily, and even administer tests on the computer. Unlike other ACOT sites where students use the Apple IIe or IIgs at school and the IIc at home, in Columbus, they use the Macintosh. This has caused some interesting problems and inspired equally interesting solutions. There is relatively little educational software available for the Macintosh, which is primarily a business computer. As a consequence, the mathematics, science, social studies, and English teachers have had to find ways to use business word processors and spreadsheets in content areas. The students have developed expertise with the kind of utility software they are likely to encounter in the job market, while the teachers have learned to tailor the software to individual course and subject needs.

These ACOT classrooms bear little resemblance to conventional classrooms with a few computers. The noise level, with machine fans, printers turning out paper copies of writing assignments, and students asking each other and teachers for assistance, is comparatively high; but concentration, excitement, and engagement are also high. Teachers rarely lecture to the class; more often they move from student to student dealing with individual problems. The students are not magically transformed; they still yawn, poke their neighbors, and daydream, but they appear to do so much less frequently. Both teachers and parents claim that students are more interested in school, more involved, and more confident. The children say that having a computer makes school work more fun, less boring, or a lot easier.

SOURCE: OTA site visits and interviews, 1987.

improvements. Polled for their interest in emerging technologies, over 20 percent of public school teachers were found to be "very interested" in networks, integrated learning systems, on-line database access, and distance learning. Perhaps even more impressive, 31 percent of surveyed teachers indicated that they ". . . would like to see publishers concentrate on developing innovative *programs that teach problem solving and higher order thinking skills,"* while 17 percent desire software that". . . reinforces and closely matches the skills taught in the basal textbook series."[5]

[5] TALMIS, "The K-12 Market for Technology and Electronic Media: A Research Report Prepared for TALMIS Continuous Information Service Clients, " unpublished manuscript, March 1988 (italics added).

If this level of enthusiasm can be sustained, new information technology may prove to be a principal catalyst of educational improvement. Some of the economic and institutional prerequisites have been the subject of preceding chapters. This chapter takes a close look at the technology itself, and asks: What can state-of-the-art information tools do for classroom learning?

CONVERGENCE OF INFORMATION TECHNOLOGIES

As indicated earlier (see chapter 2) the desktop computer is currently the prevalent electronic tool used for instruction in U.S. elementary and secondary schools. However, along with acquisition of computers, schools are gradually becoming consumers of communications and mass storage (memory) technologies. The former refer to technologies that connect students or teachers working in different places via phone lines or other electronic link; the latter are devices that store large quantities of data, such as magnetic disc or optical media. Many of the new learning tools are computer related: they must be connected to a computer to be functional. Others can be used independently, but their appeal stems largely from a principle of "interactivity" made familiar by computers. In video, for example, which is already found in over 90 percent of schools, the advantage of the videocassette recorder (VCR) over ordinary television is "time shifting. " Few teachers today would settle for less than the ability to control the timing, if not the selection of televised programs.

It is the convergence of information technologies that holds the greatest potential for the development of new learning and teaching tools. In some instances, the three principal information technologies—computer processing, telecommunications, and television (video)–have already converged into state-of-the-art instructional applications. A good example is the marriage of video and computer technologies through digital video interactive (DVI), developed by researchers at the David Sarnoff Laboratory. The Center for Children and Technology at the Bank Street College of Education has applied DVI to a project called PALENQUE, which affords users a television "walking tour" of that ancient Mayan village, as well as the occasion to control the direction and order of their tour (see photo). Perhaps most exciting about PALENQUE is that users can collect images in a "scrapbook" for future viewing and studying.

There are other examples of convergence. The Kids Network Project uses computing and communications to allow children to collect and process scientific data and transmit their findings to peers across the country.[6] Electronic teleconferencing, made possible by the convergence of television and switched (telephone) communications technologies, is commonplace in large corporations and is gradually finding applications in schools.

Distance Learning

Although instructional television has been widely used for several decades, more recent advances that

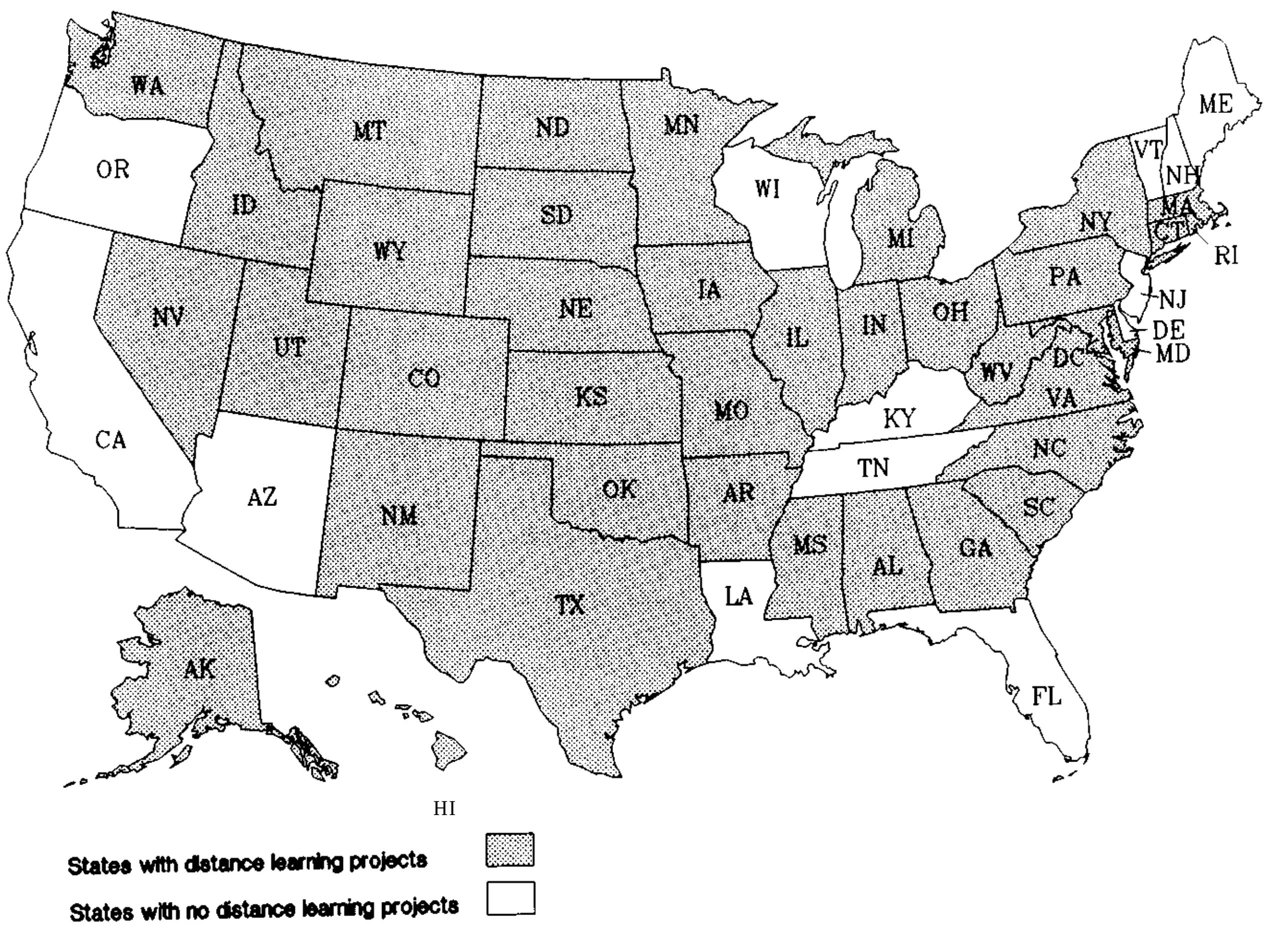
[6] For details, see Technical Education Research Centers, "National Geographic Society Kids Network Project, Annual Report, October 1986 -September 1987," n.d.

enable teachers and students to communicate interactively over thousands of miles have special appeal. There are many rural and isolated communities with teacher shortages where "distance learning" has overcome potentially significant instructional barriers. Distance learning allows students to hear and sometimes see teachers, and, perhaps more important, allows those teachers to react to students' questions and comments. The declining costs and increased accessibility of satellite technologies have enabled 35 States to support some type of distance learning program[7] (see figure 8-l). Transmission methods vary. Some involve two-way video and audio while others make use of electronic mail services for communication and evaluation of homework.

Some State distance learning programs offer courses developed and taught by local educators, while others offer courses provided by universities, private organizations, or other States. In most cases, distance learning courses are similar to regular courses, with teacher lessons, print--based materials, and tests. For example, TI-IN Network, Inc., a Texas-based private company, provides courses and staff development opportunities via satellite to more than 250 subscribing school districts and other educational agencies in Texas and in over 20 other States. During the 1986-87 school year, TI-IN offered 23 high school courses, including calculus, honors English, Latin, and computer science and over 400

[7] *Electronic Learning*, "Educational Technology 1987: A Report on EL's Seventh Annual Survey of the States," vol. 1, No. 2, October 1987, p. 41.

Figure 8-1.—States With Distance Learning Projects



SOURCE: Electronic Learning, "Educational Technology 1987, A Report on EL's Seventh Annual Survey of the States," No. 2, October 1987 hours of inservice training. Master teachers in each subject broadcast their courses from studios located in San Antonio and at California State University in Chico. Each subscribing school receives the signal via satellite. Students view the lesson and communicate with the teacher via a telephone call-back system. Students who miss a class need not miss a lesson but can watch it later on videotapes

New transmission technologies, such as fiber optic cables, will help facilitate the delivery of video, audio, and computer communications allowing many more signals to travel over one fiber than can travel over many conventional copper cables. As one example, seven rural school districts in Minnesota use a system of fiber optics, multiple video monitors, and cameras to link together classrooms up to 78 miles apart so that the teacher can see students in up to three other locations simultaneously. The originating classroom has eight video monitors and three cameras: one on the teacher, one on the students, and one above the teacher's desk for demonstration materials. Three monitors, a camera, microphone, and telephone are installed in each remote classroom.[9]

Facsimile transmission (fax) is another technology that has recently become inexpensive enough to be used in distance learning projects. Fax units now cost about $1,000. Students and teachers with access to such machines can send documents over telephone lines: each telephone in a fax link is connected to a device about the size of a VCR, which produces a printed copy of transmitted material. What normally would require photocopying and mailing of a document can be accomplished in minutes.

Networking

Networking is a generic concept that includes different types of communications links, usually computer-related. Local area networks (LANs) connect the computers in a laboratory or school to common data sources, programs, and peripheral devices such as printers. It is estimated that 13 percent of American public schools have some type of networked computer facility for instruction.[10] Typically when LANs are installed they link computers

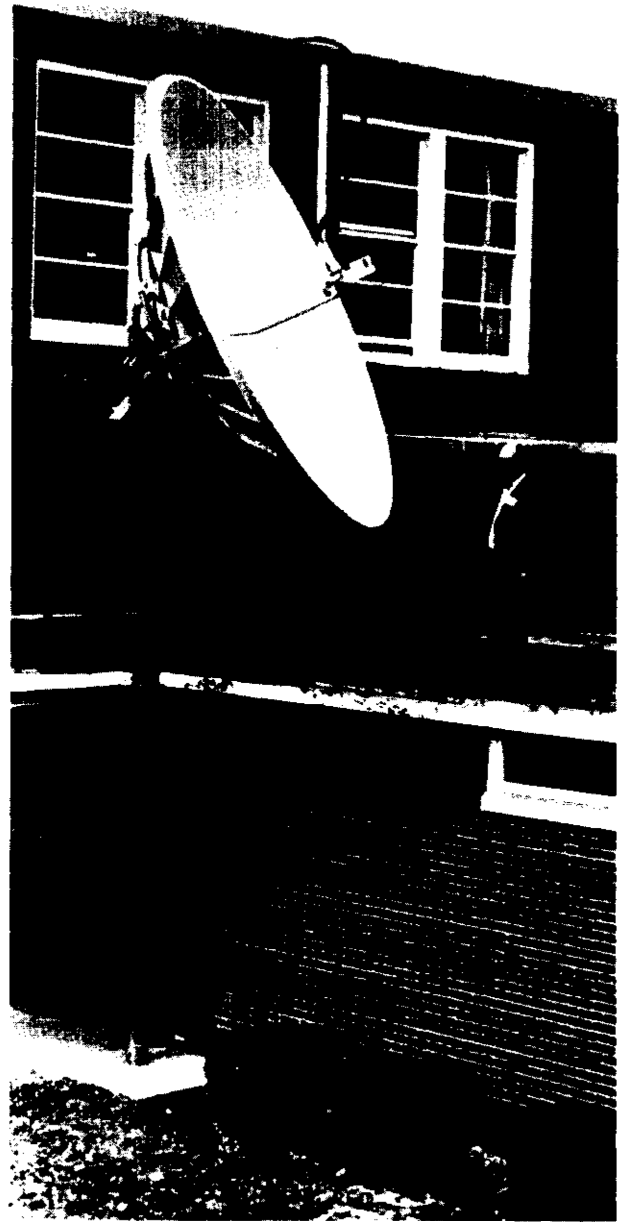


Photo credit: Agency for Instructional Technology

John M. Bedford, of the Strongsville, Ohio school system, stands beside the satellite dish that receives programming directly from public station WVIZ.

[8]Gregory M. Benson, Jr. and William Hirschen, "Distance Learning: New Windows for Education, " T.H.E. *Journal,* vol. 15, *No.* 1, August 1987, p. 63.

[9]Robin Lanier, "Interactive Telesystem Breaks New Ground," *EITV*, June 1986, p. 35. For other examples of distance learning configurations see Karen Kitchen and Will Kitchen, *Two-Way Interactive Television for Distance Learning: A Primer* (Alexandria, VA: National School Boards Association, 1987).

[10]TALMIS, op. cit., footnote 5.

already found in the school, and do not include special software for electronic mail or monitoring of student progress through computerized lessons. However, some experimental projects and recently introduced products incorporate such educational networking software.

Modems are devices that permit the transmission of data over regular telephone lines. They have led to the creation of thousands of informal networks: users sharing ideas, programs, data, and messages. There are currently over 6,000 schools (about 7 percent) with computers connected to modems.[11] Schools, therefore, are slowly beginning to take advantage of the many available on-line financial services, news, database services, and public information networks that businesses and homes have enjoyed for years. Experimental projects have also been designed and implemented that exploit modem communications for nationwide sharing of student research data (see box 8-B).

Some teachers reach their colleagues on-line from home via commercial networks like CompuServ or the Source, or via networks set up by their districts, regional education service centers, or State education agencies. Judging from lists published in the bulletin boards themselves, public access educational boards number at least in the hundreds, perhaps thousands.

In addition, there are a growing number of online services designed expressly for teachers and students working in classrooms or school computer laboratories.[12] One example is MIX, a commercial network for education operated by McGraw-Hill. In December 1987, high school students in different classrooms began participating in an international negotiations game, with each classroom representing an opposing power. Other conferences had students communicating with electronic pen pals across the Nation and in foreign countries; one allowed teachers and their students in agriculture classes to hold a corn growing contest (see table 8-1).

There are few teachers with telephone lines in their classrooms, but many of them are creatively

[11]Quality Education Data, Inc., *Microcomputer Usage in Schools: A QED Update* (Denver, CO: spring 1988).

[12]Earl Dowdy, "Computer Networks in Elementary and Secondary Education," OTA contractor report, October 1987, p. 4.

Box 8-B.—Earth Lab

The goal of the Earth Lab project, developed at the Center for Children and Technology at Bank Street College of Education, was to create an environment for collaboration in the collection and analysis of scientific data in typical school settings. The Center received $785,000 from the National Science Foundation (NSF) for research, development, and testing of the new system, which included database, report writing, and communications software, and curriculum materials on weather, climate, dinosaurs, and plate tectonics. A Harlem public school's sixth grade classrooms became the test site.

The Earth Lab system allowed multiple users to work alone or in groups and send results to their teachers or to other groups in the school, as well as in classrooms in New York, Hawaii, and Boston.

In the first year, researchers developed the prototype, and in the second year they continued development and observed results. Researchers observed a significant increase in student collaboration compared to activities that occurred before the project began:

> Students were able to work together, to think things through, to reason about the problems, and invent their own questions about the data, instead of simply reading from books or being assigned individual worksheets by the teacher.

The network provided a wider audience, and many students wrote more:

> The ease with which they could send letters to other people seems to have motivated writing in science and social studies. Students are now accustomed to using writing as a way to communicate, as opposed to writing for the purpose of giving an assignment to the teacher.

At the end of 2 years, Earth Lab was far from becoming a viable commercial product. Software was often patched together to get it running, and additional research and documentation to support development was needed. However, NSF did not fund continued work. Researchers do not believe that any commercial publisher would put the necessary work into completing and marketing the product: "The number of sales a publisher could anticipate would not justify the investment."

SOURCE: OTA site visits and interviews, 1987.

Table 8-1.—On-Line Conferences for Teachers and Students Available to Subscribers to MIX (McGraw-Hill Information Exchange), December 1987

Conference name	Description
stix. talk	Discussion and information about STIX projects
pen pals	Student pen pal conference
debate	On-line debates for high school students
student, books	Student compiled books dbase; discussion
round robin	Shared student story writing
time. capsule	Student collection of writing on one day
writers assist	Student writers' assistance by students
video	Student video exchanges
logo. pen pals	Student pen pals via LOGO projects
us. ussr	Communications between Minnesotan and Hawaiian students about USSR
Australian .reg	Registration/information on the Australian Bicentennial Project
living, history	Interact with living figures from history
other, side	Global conflict simulation for students
politics	Student interaction with politicians
orillas	Bilingual and foreign language sister classes
coordinacion	For Project Orillas Coordinators
astronomy	Minneapolis Planetarium staff on-line
water	Student water data collection/discussion
flat earth	Students v, Flat Earth Society
twistedscience	Students argue/explain science to Dr. Misconception
science	Science discussion, experts, data from 86-87
zoo	Minnesota Zoo Online
weather	Weather data and experts on-line
plant	Online plant growth data project
weather, data	Weather maps, tables, etc. from the U.S. Weather Service

SOURCE: MIX, McGraw-Hill Information Exchange, December 1987

experimenting with networks. As shown in table 8-2, there are already several exemplary efforts underway in various subject areas that exploit the convergence of processing and communications technologies. Cooperative science and writing projects for students are being developed by some groups; teachers and administrators are collaborating on curriculum research and development and writing with this technology.

The number of commercial and informal networks is expanding as the cost of operating local bulletin boards is dropping. However, important policy questions related to pricing and regulation of telephone communications must be addressed before networking becomes a regular feature of classrooms. In particular, there is the question of whether information transfer companies (such as CompuServ or the Source) should pay access charges to local telephone companies (as do long-distance telephone companies).[13]

Audiographic Communications

A different kind of communications system, called audiographic, allows teachers or students in one location to communicate with others in distant locations via a common electronic graphics system and telephone conference call. In Norwich, New York, 18 rural schools are connected by telephone lines to a central location where a teacher with a regular class has an AT&T Alliance teleconferencing bridge. Each location also has an electronic graphics system, called the Optel Telewriter 1 l-PC, a desktop device that is easily moved from student to student, The students gather around the computer, tablet, and speaker phone. The teacher or any participant can then write on the tablet or type on the keyboard and their input shows up on all of the remote graphics system screens in the network simultaneously.[14]

Broadcast

Broadcast television also has the potential to disseminate computerized information. Experiments to broadcast software to schools have been conducted by the Software Communications Service, an organization of 17 State-licensed public broadcasting systems and 5 Canadian provinces. A demonstration program in Maryland showed broadcast television's capacity to carry computer information, along with pictures and sound. It will eventually be possible to distribute instructional software to thousands of schools at a fraction of the cost of conventional distribution.[15]

An experimental project in Kentucky takes advantage of slack in the State's enormously powerful *Early Warning System* network, a Department of Defense facility that provides advance notice of incoming missiles. A mainframe computer at Western Kentucky University uses telephone lines and the emergency broadcast system to communicate with terminals at the 21 participating schools. One advantage of this communication link is its cost-effectiveness: using long-distance calls to connect to

[13]The Federal Communications Commission recently postponed indefinitely its ruling to charge access fees to information networking companies following a massive "electronic" letter writing campaign mounted by subscribers to popular information network services. Such fees would significantly raise the costs of telephone data communications and could severely hinder schools' abilities to use bulletin boards and other networks.

[14]Benson and Hirschen, op. cit., footnote 8, p. 65.

[15]Brian K. Callahan, director, Learning Technology\, Central Educational Network, personal communication, January 1988.

Table 8-2.-Examples of Electronic Networking Projects in Education

Project	Subject/activities	Participants	Sponsors
Big Sky Telegraph	Teacher training and support	114 one-room rural schools in Montana	Western Montana College; Murdock Charitable Trust; Mountain Bell Foundation; Fund for the improvement of Post Secondary Education
Bread Net	Writing project for English teachers and their students. (Teachers plan lessons via computer conference or electronic mail; students exchange compositions and information electronically y.)	1,023 students, 60 teachers in 45 classrooms in rural schools across the U.S. (2 sites in London and Lima)	Bread Loaf School School of English; Middlebury College; Apple Education Foundation; private foundations
De Orilla a Orilla (from Shore to Shore)	Bilingual education: communication through writing to promote bilingual literacy	20 classrooms in San Diego, New England, Puerto Rico, and Buenas Aires. 5 classrooms from Quebec Province to be added	New England Multi-Functional Resource Center, University of Hartford, and Quebec Ministry of Education
Kids Network	Science activities on weather forecasting, acid rain, water pollution, etc. Students/classrooms collect data, make measurements, analyze results, and share them via the network	Students in grades 4-6 in 200 classrooms, participating in a national field test and evaluation	Technical Education Research Centers/National Geographic Society; National Science Foundation
PSI Network	Technical assistance and information exchange in science education (People Sharing Information Network)	Inter- and intra-state computer conferencing system links State science supervisors and other science education policymakers	National Science Foundation; IBM

SOURCE. Office of Technology Assessment, 1988.

the schools in remote areas would be prohibitively expensive.[16]

Integration of Technology

In the future, many benefits will flow from the implementation of digital integrated networks. These systems, such as the Integrated Systems Digital Network (ISDN), provide digital communications for voice, data, and video signals, and will make computer networks and related services much cheaper.

[16]*Electronic Learning*, "Kentucky's CAI Capability," vol. 5, No. 5, February 1986, p. 10.

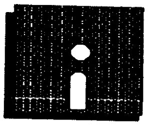
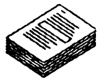
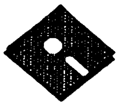
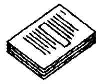
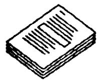
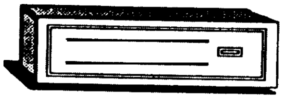
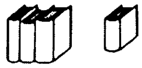
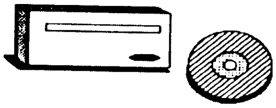
It may become possible for any home, office, or school to access any combination of computer programs and video, data, or audio information sources from anywhere in the world. Due to enormous capital costs and long-range planning necessary to install this kind of "information infrastructure," most telephone companies target full implementation of ISDN for the beginning of the 21st century, at the earliest.[17]

[17]For a discussion of Integrated Systems Digital Network see U.S. Congress, Office of Technology Assessment, *International Competition in Services* (Washington, DC: U.S. Government Printing Office, July 198'7).

ADVANCES IN MEMORY AND DATA STORAGE TECHNOLOGIES

The advent of cheap and efficient microminiaturization in electronics has spawned new digital storage media that dwarf their low-density floppy-disc predecessors (see figure 8-2). Schools lag behind other sectors, including industrial and military training, in the acquisition and implementation of these advanced technologies. Although today's typical classroom computer (such as the Apple 11-e) has much greater capacity than its forebears of 11 years ago (e.g., the Commodore PET), it is still extremely limited in the size of programs it can run (see table 8-3). And although it is possible to link desktop com-

Figure 8-2.—Evolution of Computer Storage Media

Medium	Type	Storage Capacity	Equivalent
Cassette Tape 	Magnetic Serial	30 minute tape = approx. 67 Kilobytes	13 pages of text 
8 inch Floppy Disc 	Magnetic Random Access	416 Kilobytes to 1.25 Megabytes	80 to 250 pages of text 
5.25 inch Floppy Disc 	Magnetic Random Access	143 Kilobytes to 1 Megabyte	30 to 200 pages of text 
3.5 inch Floppy Disc 	Magnetic Random Access	100 Kilobytes to 800 Kilobytes	20 to 160 pages of text 
Hard Disc 	Magnetic Random Access	5 to 40 Megabytes (typically)	2 volumes to 15 volumes 
CD-ROM 	Laser Optical Random Access	550 Megabytes	Complete Encyclopedia 

As new storage media have been developed, the density of information capable of being stored on each successive generation of storage device has increased dramatically. For example, the 5¼-inch floppy disc represents a 150-fold increase in the amount of storage per square inch over cassette tape. The 3½-inch disc has approximately twice the density of the 5¼-inch disc. The storage density of CD-ROM is approximately 1,500 times that of the 5¼-inch disc.

SOURCE Office of Technology Assessment

puters to high capacity storage devices, the latter are still not found in most schools. Nevertheless, the capacity of interactive media to store entire libraries of information and to provide high resolution graphics, full-motion video, sound, and text has attracted a growing community of scholars and educators.

CD-ROM

Compact disc-read only memory (CD-ROM) units can store over 500 megabytes of digitized data and programs. There are already some integrated instructional systems that use CD-ROM to house software.[18] Other examples include the General Post Office in Great Britain, which has placed 23.5 million addresses on one CD-ROM; the 31 volume *Grolier Encyclopedia;* and Standard and Poor's *Compustat PC Plus,* a compilation of traded companies and annual report data. Only a handful of

[18] For one example see ch. 4.

Table 8-3.—Advances in Technical Capabilities of Computers Used in Schools, 1977-87[a]

Computer	Processor	Memory	Display[b]
Commodore Pet Models 2001, 4016, 4032 (1977) discontinued	6502 8 bit	8K	Black and white; 40 characters by 25 lines
Radio Shack TRS-80 (1977) discontinued	Z-80 8 bit	16K	Black and white; 40 characters by 23 lines
Apple II+ (1977) discontinued	6502 8 bit	48K - 64K	Color; 40 characters by 24 lines; 15 color low resolution at 40 by 48; 8 color high resolution at 280 by 192
Texas Instruments TI 99/4A (1979) discontinued	9900 16 bit	16K - 64K	Color; 32 characters by 24 lines; 16 colors at 256 by 192
Atari 400/800 (1979) discontinued	6502 8 bit	16K - 64K	Color; 40 characters by 24 lines; low resolution, 40 by 24, 16 colors; medium resolution, 160 by 96, 8 colors; high resolution, 320 by 192, 2 colors; (total available palate has 128 colors)
Commodore Pet Models 8032, 8096, 9000 (1981) discontinued	6502 8 bit	8K	Black and white; 80 characters by 25 lines
Radio Shack Color Computer (1981)	6809 8 bit	4K - 32K	32 characters by 16 lines; 8 color low resolution at 32 by 16; black and white high resolution at 256 by 192
IBM PC (1981)	8088 16:8 bit	64K - 128K	Black and white; 80 characters by 25 lines; color (optional) 16 foreground and 8 background colors; high resolution, 320 by 192, 4 colors
Commodore 64 (1982)	6510 8 bit	64K	40 characters by 25 lines; 16 colors at 320 by 200
IBM PC Jr. (1983) discontinued	8088 16:8 bit	64K - 128K	80 characters by 24 lines; 4 color high resolution at 640 by 200; 16 color, medium resolution at 320 by 200
Apple IIe (1983)	6502 8 bit	64K - 128K	40 to 80 characters by 24 lines; 7 color high resolution at 280 by 192; 16 color low resolution at 40 by 48
Macintosh (1984)	68000 32:16 bit	128K - 512K	80 characters by 24 lines; black and white screen resolution at 512 by 342
Apple IIGS (1986)	65816 16 bit	256K - 1 Mb	40 to 80 characters by 24 lines; 4 color high resolution at 640 by 200; 16 color medium resolution at 320 by 200
IBM PS2 - Model 25 (1987)	8086 16:8 bit	640K +	80 characters by 24 lines; 256 color high resolution at 720 by 400

[a]These specifications represent the most typical configurations found in the classroom and do not reflect the many variations that are possible with peripheral add-on memory and color cards, for example.
[b]Manufacturer's specifications ar, not always consistent in the description of graphics resolution modes and display capabilities

SOURCE: Office of Technology Assessment, 1988

U.S. public schools, however, currently own CD-ROM units.[19]

Analog, Digital, and Optical Storage Media

Phonograph records, audiotapes, and videotapes have long been used to store pictures and sound, and have become abundant in schools as the costs of consumer electronics have dropped. The videocassette recorder for example, is now found in most schools, and offers several important features: teachers can record and play back selected broadcasts, they can rent or purchase selected tapes, and they can preview programs on their home VCRs. In addition, the VCR is a simple technology to install and use.

Laser optical storage technologies such as the **videodisc** can be used to store both analog and digital information. (For an explanation of the differences between analog and digital, see box 8-C.) The storage density of the laser videodisc is astonishing: on one side of a 12-inch disc, 54,000 individual pictures can be stored along with stereo audio and digital data.[20] In the last 5 years, laser videodisc programs have been developed for military and industrial training, and for advertising and education.

[19]TALMIS, op. cit., footnote 5, reports between 2 and 5 percent of schools with CD-ROM, depending on grade level.

[20]Ben Davis, "Image Learning: Higher Education and Interactive Video Disc," *Teachers College Record, vol. 89,* No. 3, spring 1988.

Box 8-C.--Analog v. Digital

The difference between analog and digital technology is perhaps easiest to understand through a simplified description of phonograph records and compact discs (CDs). With phonograph records, sound is picked up by a microphone that transforms sound waves into electronic waves. The electronic waves are impressed on the record in the form of fluctuations in the amplitude of the groove. When the record is played, these vibrations are sensed by a stylus (or needle) that sets up similar vibrations in the amplifier and then in the cone of a loudspeaker. The loudspeaker pushes the air and transfers the same vibrations to the ear.

With digital CD technology, the sound is taken from the microphone into a processor, broken up into miniscule entities of time, and analyzed and converted into on/off pulses. In computer terms, these on/off pulses are ones and zeros that are encoded onto the CD. This is called analog-to-digital conversion. When a laser beam scans the tracks of the CD it sends these ones and zeros to another processor which interprets them as discrete increments of sound and creates a new wave form out of them. This is called digital to analog conversion, and the resulting signal drives the speaker to reproduce the sound.

The trouble with analog signals is that they lose their strength and acquire noise as they pass through a medium (such as wire), just as sound does as it travels through the air. Moreover, each time a signal is copied it also loses fidelity. The advantage of digital technology is that after signals have been converted to on/off pulses, even though the strength of the signal may deteriorate, as long as the receiver of the information can distinguish on from off, it can reproduce the original information exactly. Therefore, no loss of fidelity will occur when digital messages are transmitted or copied. This means that each copy will be equal to the original and transmissions of information can be made with little or no degradation,

Photo credit: Optical Data Corp.

Computer-generated interactive videodiscs offer new ways to present information combining video, audio, text, and graphics, They use a computer to control the playback of audio and video from the videodisc player, sometimes adding computer-generated text and graphic materials, so that sequences can be arranged to suit the input of the viewer/participant. Schools seem to be increasingly aware of videodisc technology, but it is unclear how many own and/or use videodisc players.[21]

There are increasing numbers of videodiscs available for educational use. The Minnesota Educational Computing Corp. 1987 directory of educational videodiscs lists 360 discs, double the number entered in the 1986 edition.[22] Not all of these products were originally created for classroom use. Programs range from studies of outer space to visits to the Metropolitan Museum of Art. One product called *THE BIO SCI VIDEODISC* contains more than 6,000 still images, 2 motion sequences, maps, charts, and diagrams that can expand the typical information presented in biology textbooks. With documentation on biochemistry, cell biology, plant taxonomy, and zoology, the disc comes indexed by subject in hierarchical order and by numeric frame reference.[23]

More comprehensive efforts to develop courses on videodisc are underway. For example, the Texas Learning Technology Group[24] is developing a 160-hour, two semester, complete physical science curriculum that can be taught in grades 8, 9, or 10. The curriculum, using interactive videodisc technology, is in field test at participating district sites.[25]

Computer/Video Convergence

Compact disc video (CD-V), digital video interactive (DVI), and compact disc interactive (CD-I) are prototypes that combine computer technology and laser optical storage technology. The difference between them is the way data are encoded, accessed, and displayed. CD-V uses discs with 5 minutes of video and 20 minutes of music for viewing and listening on a home television set. (There are as yet no instructional applications of CD-V.) CD-I has no full motion video, but contains thousands of still pictures, plus graphics, sound, and data. It is also intended for the home market. Both CD-V and CD-1 will eventually come in stand-alone units, much like VCRs, which can be connected and played on standard television sets.

DVI, on the other hand, is used with an IBM-AT personal computer or equivalent. It is a fully digital compact disc, but with capabilities similar to the analog laser videodisc described above. Most important, DVI ". . . fully realizes the notion of video becoming computer-compatible."[26] It can play up to 70 minutes of limited-resolution full motion color video on a computer screen, or it can play back picture, sound, and data (but with less video). With this new technology, video can be digitally stored and played back in real time. The fact that DVI stores images in digital form means that they can also be combined or edited.

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[21]TALMIS reports approximately 6 percent of schools with videodisc; Quality Education Data, Inc., estimates 28 percent of the largest school districts with videodisc.

[22]Minnesota Educational Computing Corp., *Videodiscs for Education: A Directory* (St. Paul, MN: 1988).

[23]*Electronic Learning,* "Videodisc Includes Visual Biology Library," vol. 7, No. 2, October 1987, p. 81.

[24]The Texas Learning Technology Group is a consortium of 12 Texas school districts, the National Science Center Foundation, Inc., and the Texas Association of School Boards.

[25]Paula Hardy, director, Texas Learning Technology Group, personal communication, January 1988.

D

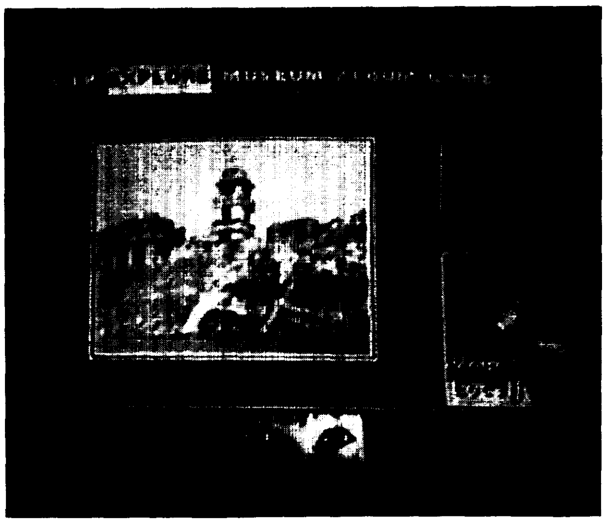

Photo credit: Center for Children and Technology, Bank Street College of Education

In this digital video interactive prototype, children can "walk" through the ancient Mayan archeological site, PALENQUE, and study items of interest as they come upon them. Dynamic eyes on the screen look left, right, up, or down as the children pan around their location on the site.

ADVANCES IN SOFTWARE[27]

The computers found in most schools have small memory capacity and slow processing times. At least 75 percent of the software titles listed in the Educational Productions Information Exchange were designed for the Apple-II line of computers, which still account for about 60 percent of the installed base in schools. The fact that these machines are sturdy, coupled with the constraints schools face in trading in and upgrading their inventories, means that software developers have been reticent to invest in sophisticated learning tools that require greater hardware capacities.

Hypermedia

Good examples of the kind of advanced software that could eventually make a difference in classroom teaching are hypertext and hypermedia. These systems represent an important breakthrough in making computers more compatible with human cognitive processes, because their storage of information is nonlinear, Just as human long-term memory consists of a complex web of associational links, hypermedia provides access to text, graphics, images, and in some cases, sound, without requiring users to specify in advance the order of access.[28] The INTERMEDIA project at Brown University is an illustration of hypermedia applied to education.[29] Users access an integrated set of text, graphics, editing, and scanning tools. Several different courses at Brown use these materials, which are linked via local area network. Hypermedia systems are substantially more complex than typical software programs, and require significantly greater computer memory capacity. Thus, while they represent a potential milestone in both the preparation of instructional materials and their application in classrooms, hardware requirements exceed the current capacity of most computers found in public schools. HyperCard, for example, Apple's recent entry into hypermedia software, was originally designed for business and only runs on Macintosh computers with at least one megabyte of random access memory (RAM).

Integrated Learning Systems

Another trend is toward greater machine control of lesson sequencing and monitoring of individual student progress. Some integrated learning systems (ILSs) include simulations and tutorials that go considerably further than electronic equivalents of drill and practice, and many cover complete curricula. At Juan Linn School in Victoria, Texas, an ILS developed by Education Systems Corp., serves 500 students a week. The software contains about 1,500 lessons in language, mathematics, and problem solving. The system manages instruction to each individual student in the school and records the progress of each student from day to day. Every child finds his or her name on the screen of a computer when entering the classroom. Although the individual computers are capable of working independently, they are usually linked in a local area network.

Videodisc Software, Compatibility, and Video Programming

Some examples of videodisc software suggest the potential for applications in education. For instance, the *National Air and Space Museum Archival Videodisc 2* contains 100,000 photographs of major air and space personalities, aircraft, balloons, airships, commercial airlines, air meets, trophies, military aviation aeronautical communications and equipment, museums, philatelic covers, and models. College *USA* shows more than 80 colleges and universities and describes their programs and facilities. *The Image Disc* archives 54,000 slides from a variety of sources, including 200 slides from the American Association of Physics Teachers repository. Not only are these databanks of images valuable for use in education and learning, they can also serve as raw materials for interactive programming.

For many reasons, especially the complexities of instructional design, creating an effective computer software package can be very expensive, costing from tens of thousands of dollars for individual programs

[27] See also ch. 6.

[28] Christopher Dede, "Empowering Environments, Hypermedia, and Microworlds," *The Computing Teacher*, vol. 15, No. 3, November 1987.

[29] Nicole Yankelovich et al., "Issues in Designing a Hypermedia Document System: The INTERMEDIA Case Study," *Multimedia in Education: Learning Tomorrow* (Cupertino, CA: Apple Computer, Inc., spring 1987); and Nicole Yankelovich et al., "Intermedia: The Concept and the Construction of a Seamless Information Environment," *Computer*, vol. 21, No. 1, January 1988, pp. 81-96.

to more than a million dollars for full courses of computerized instruction. Another factor contributing to high development costs of educational software is the incompatibility of computers found in schools. Software developed for the Apple 11 family will not run on Commodore, Tandy, or IBM computers. But in this regard too, there is a tendency toward convergence: some higher level operating systems allow programming in a "machine-independent" environment, so that programs can be sent from one hardware type to another with little or no change. These systems are generally too large to run on the computers commonly found in schools today; but there is reason to believe that continued research will yield an affordable solution to this problem of system integration.[30]

[30]See also ch. 6 for a brief description of the research program on system compatibility underway at the Institute for Defense Analyses.

Creating effective video programming, especially interactive video production, is very expensive. It requires complex instructional design and software programming, and multiple forms of video production.[31] For this reason, the major markets for interactive videodisc are in industrial and military training and medical simulations.

[31]It has been estimated that the average cost of producing a single interactive video program for industrial or business applications is $150,000. James A. Lippke, "Interactive Video Discs: Entering the Mainstream of Business," *Educational and industrial Television, vol. 19, No. 8, 1987,* p. 12. The Texas Learning Technology Group estimates that their physical science curriculum on interactive videodiscs will cost about $4 million to develop. Hardy, op. cit., footnote 25.

SUMMARY AND CONCLUSIONS

Interactive technologies for processing, storing, and communicating information have made their place in American business, science, and the military, and stand now at the doorway of the American public school.

More advanced computer logic and memory systems could allow students' computers to run several programs at once, to move information from one application to another, to communicate ideas to classmates and pen pals around the world, and to integrate the content of one lesson into another. Improved graphics, animation, and sound, as well as real-time video, could make subjects of study come alive. On-line multimedia libraries could provide information for class research projects. Increased access to other children, not only within the United States but all over the world, could broaden students' appreciation of different cultures. Experts from many disciplines, master teachers, and even community leaders and politicians could become available to inquiring classrooms. Telecommunications could allow students forced to remain home due to illness or weather conditions to connect with the teacher or with school programs to make up for lost time. Distance learning programs could support isolated populations of students who are underserved in certain subjects.

These technologies could also serve many other purposes and could become the center of new services to schools, teachers, and adults across the Nation. Software could be delivered on television signals. Instruction in many specialized areas of the curriculum could be broadcast to teachers and students, with exercises, testing, and help available through the telephone by voice or modem. Inexpensive video technology—small portable cameras that contain video recording devices—could be used by students to create audio/visual essays, or to gather images for use with computers. Students might combine pictures shot in their backyard with images received from databanks over the telephone, and written essays composed with word processors could incorporate graphs compiled using spreadsheet programs and computerized measurement devices.

In the words of a leading computer scientist, "The way computing has permeated the fabric of purposeful intellectual and economic activity has no parallel."[32] Information technologies have transformed the worlds of business, science, entertainment, the military, government, law, banking, travel, medicine, and agriculture. The question is whether they will make as deep a mark on classroom learning—and how.

[32]Abraham Peled, "The Next Computer Revolution," *Scientific American, vol. 257, No. 4,* October 1987, p. 57.

EPILOG

Most historians of technology would agree with Nobel Laureate Simon that the computer is no ordinary innovation. Indeed, the most profound question facing American society today is whether its institutions can adapt to a world that has changed more dramatically in the last 30 years than in the preceding 30 decades. Our schools are assigned the monumental task of arming young people to compete in this changing world: they are society's potters entrusted with the clay of children's minds. But there is abundant evidence that the potters' tools are rusted, and almost unanimous consensus that things must change.

Most educators believe that the new tools of the information age can be pivotal in shaping the American classroom to fit its ever-changing environment. For others—educators, technologists, and historians alike—there is a gnawing sense of deja-vu, a fear that relying on new technology to upgrade classroom learning signifies the triumph of hope over experience.

How will future historians judge the choices made today? Will their data consist mainly of teachers and students using new tools to push the frontiers of learning? Or will effective schools, in which computers and other technologies realize their full potential, always be the exception? To illustrate the critical crossroad at which we now stand, OTA has received permission to reprint the following excerpt from a recent paper by Shirley Malcom, a prominent authority on schooling and technology in America:

A Tale of Two Futures[33]

Raul Gomez walked in the door of his inner city middle school classroom rather down in the dumps. "Here we go again," he thinks. If it were not for the compulsory education laws and the possibility that his mother could be arrested if he were truant, he wouldn't bother to come at all. He spends a lot of his day sitting in front of the computer doing endless drill and practice.

To increase educational efficiency and to help Raul's teacher cope with 35 students, the district put computers in their classroom. Some of the children work on the computers while the teacher works directly with the others. For 14 students, English is not their native language. Among them, there are 7 different languages spoken. If he had to go through another set of practice problems and subject/verb agreements, he'd go crazy. Occasionally, just for a change of pace he'd deliberately answer a question incorrectly so he could see the funny little graphics built into "motivate the user." If he didn't get it right after a couple of times, "the solution" was explained to him. He had figured out other ways to solve the problems, but for some reason the computer never explained it his way. They both got the same answer, but he knew there must be something wrong with his way because the computer never did it like that.

Raul had thought computers were going to be a lot more fun. He first saw one at the Saltman's house, the family for whom his mother worked. He had gone with her during the summer to help with the yard work and had seen the games and the simulated science experiments. There was an electronic mail feature that had been set up to help team members keep in contact as they prepared for the international mathematics competition. But somehow, at his school it just wasn't the same. He asked Ms. Russell about those neat things he had seen at the Saltman's, but she had said that the students weren't ready for that yet. Besides, doing those things required more time on the computer and there were not quite enough machines to go around.

If only his family had the money to buy its own computer! But there was barely enough money to buy food and clothes and pay the rent for the four of them—Raul, his younger sisters, and his Mom. There was so much that he wanted to know about how the world worked, but in his class they never seemed to get to any of the exciting stuff-they always seemed to be getting ready for the next competency test, always having to cover more pages in the textbook. As soon as he could, he was going to quit school and go to work and help his mother with the girls. Maybe he'd get back to school one day. If there were more here for him he wouldn't leave, but it's just a waste of time. What good does it do his family if he knows the names of all the dead presidents?

[33] Shirley M. Malcom, "Technology in 2020: Educating a Diverse Population," paper prepared for the Conference on Technology in Education in 2020: Thinking About the Not-Distant Future, Harvard University, Educational Technology Center, Oct. 15-17, 1986. This conference was supported in part by OTA. This paper and others presented at the conference will be published in Nickerson and Zodhiates, op. cit., footnote 3.

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He had seen a TV program once about Mayan mathematics and about the sun dagger in the Southwest that native people developed to tell the arrival of the different seasons of the year. He asked his teacher about these things, but she said that they had to stay on schedule or they wouldn't cover the material in time for the science test.

Sonia entered her inner city middle school classroom elated. She had just "published" her first book, complete with illustrations. As soon as it had been bound, it would be put in the media center. Imagine that, Sonia Ramirez, AUTHOR. And to think, just 3 years before when she and her older brother and sister had come from Puerto Rico, she couldn't speak, read, or write English, and now she had a book in English and Spanish. The speech synthesis and translation features on the computer had really helped her develop proficiency in both languages. There were enough computers to go around and enough textbooks so that everyone could use them. Her book was about rain shadows. It was fun when you could do science, geography, English, Spanish, and art at the same time. She had to do a lot of work on her book at home, but that was all right. Sonia had been taking home a loaned computer since she had first entered school here. Computers are a big part of Sonia's life and the lives of her classmates. Her friend Hilda has a computer that speaks for her (and in a girl's voice!): Hilda is nonvocal because of cerebral palsy. Hilda has to use her computer for writing, too.

Sonia is learning to play the synthesizer in the school orchestra. The wide variety of software that she can borrow from the library (or that comes with the books) lets her look at all kinds of things that interest her. She and her classmates have developed software, too, which is included in the middle school computer network in their school system.

Sonia and Hilda are interested in birds. Their *Peterson's Field Guide* has a videodisc that goes with it so that they can study the birds in flight, listen to the songs and learn more about their life histories. It really helps to be able to go back and forth between similar species and to have the differences between them highlighted.

Raul and Sonia live in two very different futures. Raul's future was created by extrapolating from the present: the present trends in education, the present educational goals for poor, disadvantaged, and minority students, the present way the technology is used in educating these students. For Raul, overall trends in the technology matter very little when he has so few appropriate tools for his education, and when no concerted effort has been made to address his educational needs. Differences in the educational use of technology further separate the worlds of the Gomez and the Saltman families. On the other hand, Sonia Ramirez has been empowered by education, and the technology has made that education more meaningful and more accessible. At present, Raul's future is more probable though not very desirable. Achieving Sonia's future will not be easy.

Photo credit: Neldine Nichols, Wisconsin Department of Public Instruction

What kind of future will we choose for our children?

Appendixes

State Activities in Educational Technology

Introduction

Historically, States have shared responsibility for the education of America's children with local communities. During the past 20 years, the State role in education has expanded. Many now establish broad curriculum objectives, set standards for teacher and student proficiencies, provide funding to schools and districts, support special projects, and monitor local performance. More recently, States have become key players in educational reform, initiating a range of policies and programs. Along with an expanded role in education overall, States have become more involved in educational technology.

In the early 1980s, only a handful of States were actively involved in educational technology. Today nearly every State is. State activities vary, reflecting the diversity of educational traditions, priorities, resources, and needs. Some States have passed specific mandates or have imposed detailed controls on teachers, schools, and districts, while others have enacted a mixture of initiatives designed to build local capacity and encourage local decisionmaking.[1] In general, State technology policies and activities are concerned with four areas:[2] 1) hardware acquisition; 2) software acquisition, evaluation, and distribution; 3) staff training and development; and 4) integrating technology with ongoing instruction.

In October 1987, OTA sent a questionnaire to the agency or individual responsible for educational technology in all 50 States and the District of Columbia.[3] By February 1988 all States responded. OTA staff also contacted State technology directors by phone where clarification or elaboration was needed. In addition, OTA examined State's written responses to *Electronic Learning's* 1987 Survey of the States and the 1986 State Technology Profile Survey conducted by the Council of Chief State School Officers. Additional information about State technology efforts, primarily in the area of software, was obtained from data collected in 1987 by the National Governors' Association.

[1] OTA State Educational Technology Survey, 1987. *See* also Janice H. Patterson, Center for Policy Research in Education, University of Wisconsin-Madison, "Computers in Schools: State Policy Objectives and Policy Instruments," unpublished manuscript, December 1987.

[2] Patterson, op. cit., footnote 1.

[3] To simplify reporting, the District of Columbia will be counted as a State in the following discussion.

Organizational Structure, Planning, and Funding for Technology

- Forty-one States have a technology division or staff position for educational technology.
- Twenty-four States have a long-range plan for educational technology and plans are under development in 13 other States (see figure A-l).
- Forty-four States allocate funds specifically for educational technology or make other State funds available (see figure A-2),[4]
- Forty-nine States use Federal funds for technology: Chapter 2 predominates, followed by Chapter 1 and Title II.
- At the local level, funds for technology are provided by the local district, State, and Chapter 2 (see figure A-3).

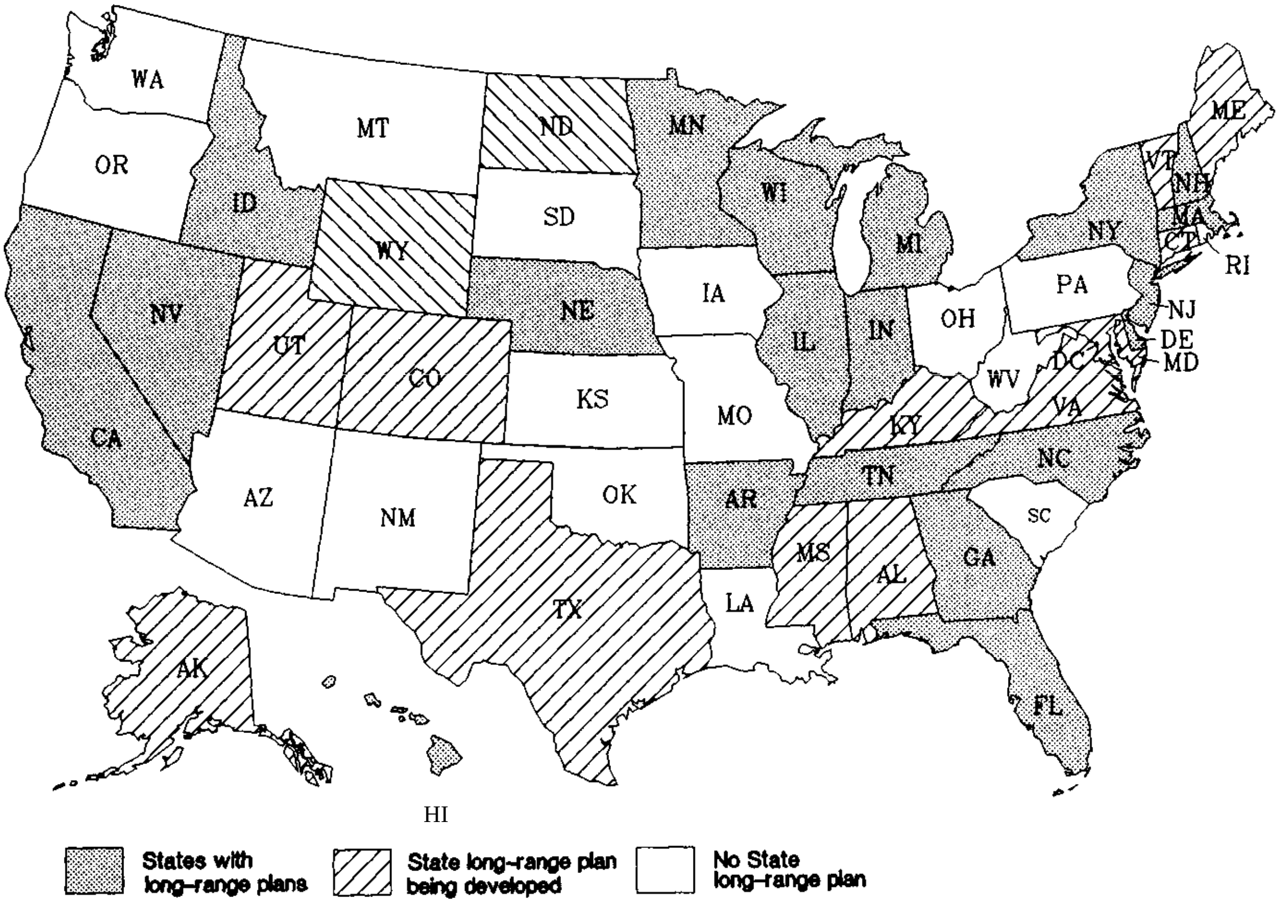
The function, responsibility, and organization of State technology divisions or staff positions vary across the country. Most are part of the State Department of Education (SDE). In some States, a consultant provides workshops and technical assistance to teachers and districts. In others, the technology division works with other SDE units to offer curriculum consultation and software preview assistance to educators. And in some States, the technology unit awards grants, provides technical assistance, and administers several separate programs.

Planning for technology is an important part of the State role. Most long-range plans and those being developed are initiated by SDEs. Others are initiated by the legislature, the State Board of Education, or in one case, a Governor's Commission. The plans reflect each State's approach to technology, educational policy and governance, and the relationship with local school districts. Some plans suggest curriculum approaches while others outline detailed strategies for implementation, or establish graduation and teacher certification requirements.

While some States have made large investments in educational technology, in most States, Federal funding, particularly Chapter 2, is an important source of support for educational technology at the State and local level. State funding for educational technology usually is mixed with finding from other sources including the Federal Government, business and industry, software publishers, hardware vendors, and private foundations.

[4] Funding is pending in two States.

Figure A-1.—State Long-Range Planning for Educational Technology



SOURCE: Office of Technology Assessment, State Educational Technology Survey, 1987.

Funding is by no means uniform or steady. Specific allocations for technology ranged from $41 million to less than $200,000.[5] Several States provided one-time only allocations, while others have experienced serious budget reductions. Two-thirds of the States reported that insufficient funding hampered the implementation of technology. Needs mentioned were training, hardware, software, and long-term funding to allow time to implement technology and address equity concerns.

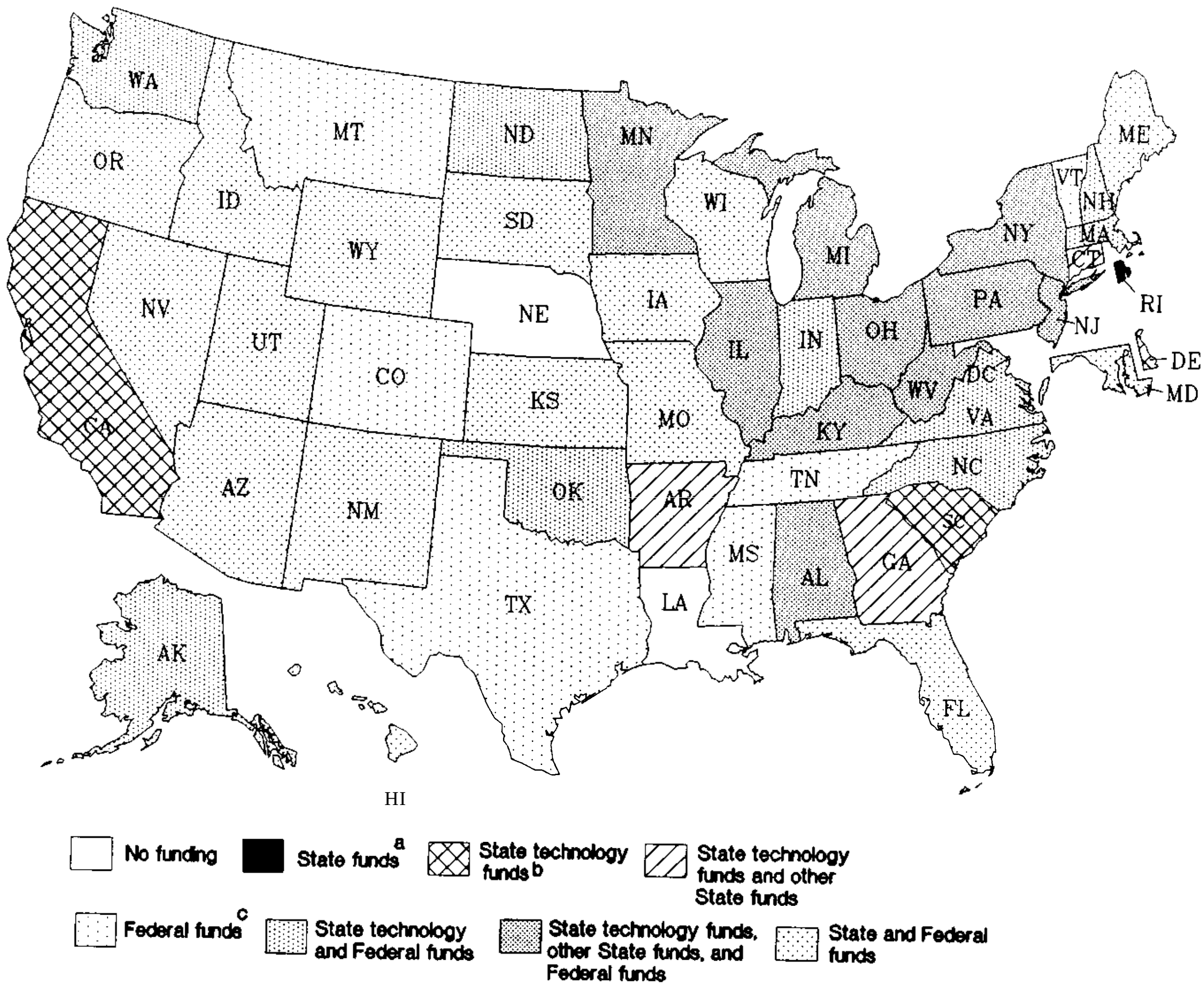
Although many States encourage wider use of new learning tools, few have sufficient resources to deal with changing technology, and even less to support a significant increase in access. States are beginning to support development and demonstration projects, but the scope of these efforts is limited. With a few exceptions, the major focus of State pilot and demonstration projects is on finding better ways to fit technology into the existing curriculum.[6]

Faced with competing priorities and financial limitations, States are taking a pragmatic approach to influence and encourage the use of technology in the schools. Most States focus resources in one or a few areas—training teachers, distributing hardware, supporting administrative uses of technology, evaluating software, and distance learning.

[5]OTA survey results reflect Information provided by respondents. In some States, particularly larger ones, accurate funding data was not available and responses were estimated.

[6]The National Governors' Association made a similar conclusion about State educational technology efforts: National Governors' Association, *1987 Followup Report* to *Time for Results: The Governors' 1991 Report of Education* (Washington, DC: 1987), p. 25. "Current state activities in the area of technology seem to be continuing earher initiatives . . . the process is characterized by adaptation and gradual growth rather than dramatic invention or Innovation. In effect, we do not have evidence that states now rely on technology in efforts to restructure their schools. "

Figure A-2.—Sources of Funding for Educational Technology at the State Level



[a]General State aid is the source of State funding for technology in Idaho, Iowa, Kansas, Nevada, Oregon, South Dakota, Wisconsin, and Wyoming. It is one of the sources of funding in New Jersey and West Virginia.
[b]State technology funding is pending in Connecticut and West Virginia.
[c]25 States report using Chapter 1 funds for technology; 34 report the use of Chapter 2 funds; and 23 report the use of Title II funds.

SOURCE: Office of Technology Assessment, State Educational Technology Survey, 1987.

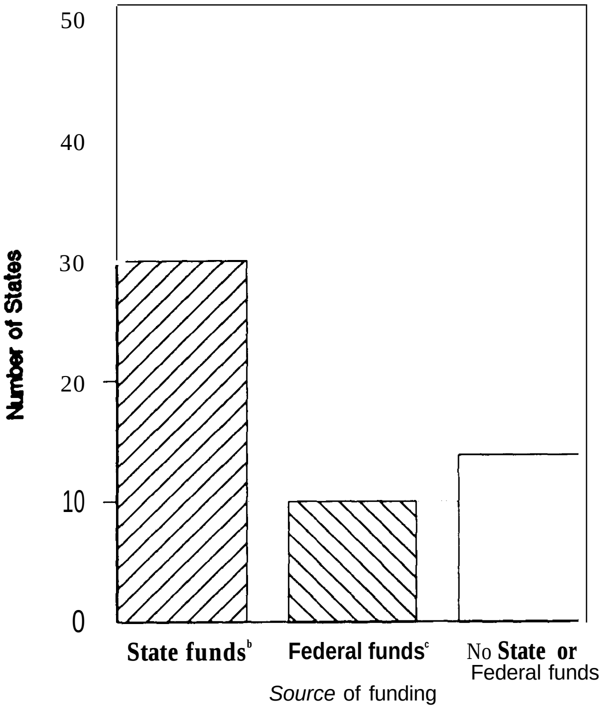
New Institutional Arrangements and Policies

Innovative policies and new institutional arrangements can support the use of education] technology. Because the size of the investment needed to implement and support educational technology programs is large, there is a need to build State, regional, and local partnerships and to enlist the involvement of colleges, universities, business and industry.

In Arkansas, for example, business and education leaders support the technology initiative. Indiana provides low interest loans to districts for hardware. And in Maine, Federal Chapter 2 funds were used to create a statewide computer consortium supported by member districts.[7]

[7]Other innovative policies and collaborative efforts are described throughout the report or are included in the following State summaries.

Figure A-3.—State Estimates of Major Sources of Funding for Technology Used by School Districts[a]



[a]State technology coordinators were asked to select the top three sources of funding used by districts.
[b]State funds used for technology by districts include: 1) funds for technology allocated to all districts; 2) grants for technology; and 3) grants that may be used for technology.

SOURCE: Office of Technology Assessment, State Educational Technology Survey, 1987.

Many of these innovative policies and partnerships suggest alternative approaches to support the use of technology in education. Through dissemination and collaboration, these creative efforts and ideas could serve as models for other States.

State Hardware and Software Activities

- Thirty-three States have developed procedures that allow school districts to purchase hardware at reduced prices.[8]
- Twenty-four States negotiate agreements with software publishers to purchase administrative or applications software at reduced prices.[9]
- Over 60 percent of the States support software evaluation activities.[10]
- Twenty States either fund or offer technical assistance for the operation or development of systems to distribute software electronically.[11]
- Thirty States are involved in curriculum development projects using commercial software.[12]
- Seventeen States fund or offer technical assistance for development of educational software.”

Expanding access to technology through acquisition, evaluation, and distribution of hardware and software is a State concern. In addition, some States are playing a key role in aggregating purchases of hardware and software, either by negotiating directly with hardware vendors and software publishers, or by supporting or facilitating regional and district efforts.

States also help to provide information about software by supporting software preview, evaluation, and dissemination at the State and regional level. Some States also influence (either formally or informally) the types of software schools use through the development of curriculum guidelines or support for certain instructional approaches. With a few exceptions, the extent of State involvement in software development is limited to small scale projects.

Duplication of Effort: Need for Collaboration and Information

With each State deciding individually how to use technology, effort is being duplicated across the country. This may be especially true in regard to software evaluation and arrangements with hardware vendors and software publishers. The States share a need for more information about hardware, software, and about ways technology can be used to enhance learning in schools and classrooms.

The Software Evaluation Exchange Dissemination Project (SEED) is a multistate collaborative project coordinated by the Southeastern Education Improvement Laboratory, one of the national education research laboratories.[14] SEED facilitates software evaluation for six

[8]National Governors' Association, “Technology's Role in Educational Reform,” *Capital Ideas*, July 1, 1987. Results of an National Governors' Association survey conducted in 1986-87.

‘Ibid.

[10]*Electronic Learning*, “Educational Technology 1987, A Report on EL's Seventh Annual Survey of the States,” vol. 7, No. 2, October 1987.

[11]Office of Technology Assessment, based on Electronic Learning, 1987 State Technology Survey.

[12]Ibid.

[13]Ibid.

[14]Project SEED, initiated i. 1984, has passed through three phases of development, identified by changes in the project's name. The first phase, Software Evaluation Exchange and Design, involved conceptualization and acceptance of the evaluation process. The second phase, Software Evaluation Exchange Development, was a period of training and refining procedures. The third and current phase, Software Evaluation Exchange Dissemination, involves expanding to other States, increasing the number of evaluations performed, and disseminating results. A 1987 evaluation concluded that the human element is key to a successful collaborative effort like SEED and that sufficient time and resources must be allocated to develop a successful process.

Southeastern States (Alabama, Florida, Georgia, Mississippi, North Carolina, and South Carolina). Over several years, SEED has trained educators and has helped participating States evaluate software and share information. Each State then distributes evaluations independently to local school districts. Several other States are interested in joining SEED and it is expected that a membership fee will be charged for States outside the southeast region.

Another effort to bring States together was initiated by the Council of Chief State School Officers (CCSSO) in 1983, CCSSO's National Technology Leadership Project, funded under a 2-year grant from the National Institute for Education (NIE), provided States on-line information about educational technology products, collected information about State activities and needs, conducted two national conferences, and began to establish links among States, Federal agencies, and other organizations involved in educational technology. Perhaps most importantly, the projects created a forum for State collaboration and discussion of major policy issues. The project ended in 1986 when the NIE grant ended.

Equity and Access

One of the main justifications for State involvement in education is to foster equal access to educational resources for all students. In some States, efforts to provide equal access to technology resulted in spreading technology thinly. For instance, one southern State's goal is to put enough computers in the schools to provide 1 computer for every 50 students. Other States address equity concerns by allocating funding for technology to all school districts on a formula basis, or setting up computer laboratories in each school that students can use for a limited amount of time each day, month, or year. States report that these approaches do not necessarily result in equal access to technology; wealthier districts continue to have more resources to use for hardware, software, and teacher training.

Several States are taking a somewhat different approach, concentrating resources and targeting specific needs of selected groups of students. Many of these States support using technology to teach basic skills to low-achieving students, or to provide instruction to disadvantaged and underserved students through, for example, distance learning. Other States implement instructional packages or integrated learning systems for certain grade levels or groups of students. Approaches such as these represent an acceptance that technology can be used for basic skills instruction with certain groups of students. They raise questions, however, about providing equal access not only to hardware, but to how technology is used with different groups of students, particular whether it is being used to enhance the higher order thinking abilities and academic performance of the disadvantaged.

Teacher Preparation, Training, and Professional Development

- Eighteen States require and eight recommend that teachers seeking certification take computer-related courses or become familiar with using technology in instruction. ”
- Three States require and 17 States recommend some form of inservice professional development in the use of technology.
- Almost every State provides or supports inservice technology activities through a combination of ongoing activities and periodic efforts.[16]
- Over three-quarters of the States sponsor technology conferences and half support training through regional education or technology centers.
- Twenty-two States now use or plan to use electronic networks, interactive television, videotape, or other technologies to provide inservice training and assistance in the use of technology.
- Thirty-four States allocate funds specifically for inservice technology training or make other funds available which may be used for technology training (see figure A-4).[17]
- Ten States use Federal funds for inservice technology training, primarily Title 11 and Chapter 2, but also Chapter 1, vocational education, and special education funds.

Most teachers receive technology training through their district; however, the State is an important source of training programs and assistance in many States. Regional centers, often partially funded by the State, are playing a growing role in providing technology training to educators along with other education services. Funds for training, as for other educational technology efforts, vary by State and come from a mix of sources: State funds for technology training; professional development grants; funding that flows through regional centers or districts; general State aid used at local discretion; and Federal dollars (e.g., Title II, Chapter 2). Of the 20 States” that allocate funds specifically for technology training, annual funding ranges from $15 million to less than $20,000.

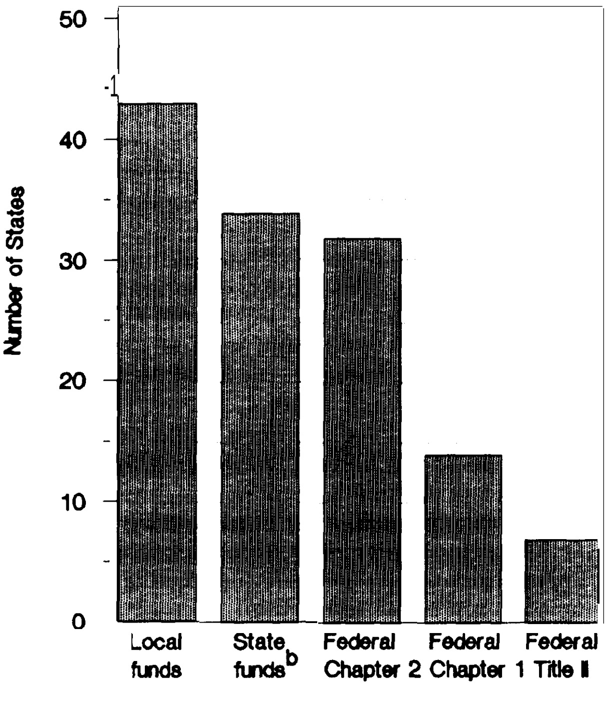
[15] In six States, these requirements apply only to teachers in certain areas such as business, computer, or media education.

[16] Some States provide training, information, consultant services, or facilitate training at the regional or local level, but do not allocate funding for technology training.

[17] State funding for technology, training in Utah is pending study and recommendations.

‘‘Nlnc of these States make other State or Federal funds available as well.

Figure A-4.—State Estimates of Sources of Funding for Inservice Technology Training[a]



[a]State technology coordinators were asked to select the top three sources of funding for technology at the local level.
[b]State funds include: 1) funds for technology training; 2) Professional development funds or grants; 3) funds that flow through regional centers or districts; and 4) general State aid used at local discretion.
[c]Federal funding includes Title II, Chapter 1, Chapter 2, and Special Education funds.

SOURCE: Office of Technology Assessment, State Educational Technology Survey, 1987.

State Research, Development, and Demonstration Activities

Sixteen States fund or provide technical assistance to an educational technology project with a research or evaluation component.[19] In addition, some States report supporting demonstrations and pilot projects in the context of curriculum development or software activities. Overall, however, research and development supported by the States is limited. Most States do not have the means to fund scientific research on learning and educational technology or to develop advanced software.

Yet, State research projects are important because, for the most part, they focus on questions about implementing technology in schools and investigate the use of technology to serve defined educational needs. Some States support projects on a limited scale before a larger investment is considered, or work with vendors and the private sector to establish pilot projects. Others award grants to schools, districts, or teachers for innovative projects or school improvement which may involve technology. Some of these projects have an evaluation or research component while others do not, but in all projects technology is being used by teachers or students in a variety of "real world" settings.

Some Examples

In Minnesota, evaluations of teacher training efforts found that the most successful programs are those in which teachers work with technology-using peers. Large, one-time group training sessions conducted by vendors were found to be the least successful. Alaska sponsored two classroom-based research projects to study the use of technology in instruction. One project focused on using technology to teach writing and the other on increasing inquiry learning in science. Participating teachers were trained in classroom-based research techniques and kept journals describing their teaching experiences and observations in the classroom.[20]

Kentucky initiated Project Vision, a pilot project to develop a videodisc program to teach remedial mathematics skills in grades K-2, based on the Kentucky Essential Skills Test. The project was supported to a large extent by private donations and in-kind support from vendors.

Recently, research has begun in five model school sites in California. The goal is to study long-term effects of using technology in instruction. Annual finding for the projects is contingent on the total funds approved by the Governor for the State's educational technology activities.

Technology, Curriculum, and Educational Reform

Many States establish curriculum requirements or develop optional guidelines for districts. The current focus is "integrating technology into the curriculum;" however, interpretation of this concept varies. California, for example, supports the use of technology as an educational tool. It initiated the $2 million Technology in the Curriculum Project to help educators locate high-quality software and video programs and integrate them into the

[19]States reporting research and development activities: Alaska, Arkansas, California, Delaware, Indiana, Kentucky, Maryland, Minnesota, New Hampshire, New Jersey, New York, Texas, Utah, Virginia, and West Virginia. Additional research projects are pending in two States, Washington, DC and Florida.

[20]A publication, *Hand in Hand: The Writing Process and the Microcomputer* was published by the Alaska Department of Education in 1985 as a result of the classroom-based, Computer/Writing Skills Project. Currently, there are no State funds to publish a similar document about the Inquiry Science Project, which was funded by the State during 1986-87. The State is looking into using Federal or other funding sources. The Alaska Department of Education also hopes to use Federal funds to undertake similar classroom-based research in mathematics.

curriculum, In Delaware, on the other hand, a 1984 State plan mentions integrating technology into instruction, but is more specific about computer science and computer-assisted instruction, and the State has provided funding for these areas." In other States, integrating technology into instruction has been interpreted to mean matching software with basic skills competencies outlined by the State, or using technology to supplement the existing curriculum.

In some States, activities and new initiatives involving technology are tied to educational reform. In Wisconsin, where there is a tradition of strong local control of education, legislation resulted in new standards and a series of curriculum guides requiring changes in both the content and delivery of instruction. SDE sees technology as an important component of overall school improvement and local districts are encouraged to integrate technology into the curriculum. At the same time, no State funds have been allocated specifically for technology; instead, the State funds regional educational service centers, and districts receive about 50 percent of their funding from the State. Beginning in fall 1988, the State will try to influence districts that do not comply with the State standards, including those regarding educational technology.

Texas' approach to technology also reflects the State's approach to educational reform: the creation of specific requirements and regulations. Teachers seeking certification in Texas are required to take a course on educational computing and technology or demonstrate proficiency. All districts must teach computer competencies in elementary schools. Curriculum guidelines under development are expected to include keyboarding, information processing, and using computers to develop problem solving skills. In addition, every student in Texas must complete at least one semester in computer literacy in seventh or eighth grade. This course specifies applications, awareness, and introductory programming. There is also a separate advanced high school diploma that includes courses in computing.[22] Texas has not funded local implementation efforts but has funded several pilot projects with State and Federal dollars (primarily Chapter 2). State requirements for elementary computing and local planning have been proposed and are likely to be developed in 1 to 2 years.

Technology is changing rapidly and States have many choices about how best to take advantage of the potential of technology in education. Curriculum requirements, instructional priorities, and institutional arrangements influence how technology resources are used. States may find it difficult to change policies or encourage different instructional approaches after investing money, people, and effort. Rigid, narrow, or outdated educational policies may make innovative and effective uses of technology difficult to implement in the future. More collaboration between States, educators, researchers, and developers could help States articulate needs, identify newer technologies and instructional approaches, encourage flexibility, and influence further development.

[21]Delaware, *State Plan for the Use of Computers in K-12 Education* currently is being revised and the new version may give greater attention to the use of computer applications in regular classrooms.

[22]There are no educational technology requirements for a regular high school diploma.

State Profiles

Alabama

State position/unit: Yes (1983)
State plan: Being developed
Key actors: State Advisory Committee
Funds available through the State for technology activities: State technology;[23] State education;[24] Federal
Source of funding in most districts: State grants that may be used for technology
State training policies: None
State funding for technology training: None
Way most teachers receive training: State[25]
Most important State action: $8 million in 1984 for hardware/software
Major changes in past year: Task Force to develop State plan
Barriers: Cost; State plan

The 1984 State educational improvement plan encouraged districts to include the use of technology in grades K-12. A $12 million appropriation allocated 70 percent of these funds for hardware and software purchase. Due to a revenue shortfall, only $5 million was made available in 1985-86. Federal Chapter 1 and Chapter 2 funds were also used to purchase hardware and software in 1986-87 and 1987-88.

In 1986-87 $750,000 was allocated for a statewide telecommunications system to connect local districts and SDE. The network now connects the State and all 130 school districts. A $250,000 allocation in 1987-88 continues training and provides maintenance. Future plans include statewide implementation of a student management system to standardize scheduling and recordkeeping.

Alabama participates in SEED, a multistate model for software evaluation and evaluation exchange.[26]

[23]*State technology* funds can include State funds earmarked for technology that go to all districts or State technology grants awarded to specific projects, districts, or schools.

[24]*State education* funds can include State grants for educational improvement or reform, general State aid, staff development funds, or State funds that flow through regional centers or other entitles.

[25]A State may provide training, information, consultant services, or facilitate regional activities but may not allocate funding for technology training.

[26]See discussion of SEED above.

Alaska

State position/unit: Yes (1980)
State plan: Being developed
Key actors: Legislators; professional teacher associations
Funds available through the State for technology activities: State technology; Federal
Source offending inmost districts: District/general State aid
State training policies: None
State funding for technology training: None
Way most teachers receive training: District
Most important State action: Establishing computer and instructional television projects (1980)
Next steps: Explore distance learning
Major changes in past year: Most funding and staff reduced
Barriers: Funding; staff; political support

In 1986, the State's satellite-based network for instructional television (ITV) (the Learn Alaska Network) was cut and staff for educational technology significantly reduced. The State now maintains an ITV support system and is planning for the use of distance delivery. An Alaska studies course is being developed for distance delivery. One pilot project uses audioconferencing and electronic mail in addition to video. The State also produces a phone call-in television series, "Talk Back," using Title II funds. The State supports a project investigating the impact of computers in science education. In previous years, several classroom-based research projects trained teachers to assess the impact of technology in their classrooms.

Arizona

State position/unit: Yes (1981)
State plan: No
Key actors: State Advisory Committee; teacher organizations; parents; district computer coordinators
Funds available through the State for technology activities: State education; Federal
Source of funding in most districts: District
State training policies: None
State funding for technology training: None
Way most teachers receive training: School
Most important State action: 1983 bill establishing State technology role and clearinghouse
Major changes in past year: None
Barriers: Lack of legislative awareness about technology

Legislation passed in 1983 defined the State role in educational technology and created a clearinghouse for software and information, but as yet, no State funds have been allocated for technology through SDE. Three staff members assist schools with volume purchases for technology and provide training, support, and software evaluation services. General education funds are used to purchase software for evaluation and preview.

The Arizona School Services Through Educational Technology Project (ASSET), operated out of the State's public broadcasting stations, provides ITV programming and support services to schools. Several instructional packages that include software are available through ASSET. Funding for ASSET comes equally from member districts and the State. Federal Title II funds are also used by both districts and the State. As schools install satellite dishes the State expects to become more involved in distance learning.

The State Computer Services Unit provides ongoing training to educators through a magnet school in Phoenix and in districts upon request. In 1987-88, $17,500 (Title II) will be used to train 200 mathematics and science educators from rural districts in the use of technology.

Arkansas

State position/unit: Yes (1983)
State plan: Yes (1984; revised 1986-87)
Key actors: Business community; Governor; Chief State School Officer
Funds available through the State for technology activities: State technology; State education
Source of funding in most districts: District
State training policies: Preservice (required for media teachers); inservice (recommended)
State funding for technology training: Yes
Most important State action: IMPAC; distance learning; vocational education guidelines; high school computer science requirements; defining levels of inservice
Major changes in past year: Increased leadership by Governor and State Education Director
Barriers: None

In 1983, the Instructional Microcomputer Project for Arkansas Classrooms (IMPAC) was created through legislation. Supported by the State and the business community, IMPAC has developed software and implemented several models of computer-managed and computer-assisted instruction combined with classroom instruction to teach basic skills. Software and lessons are linked to the State's basic skills list and costs are closely monitored. IMPAC projects have been implemented in 136 schools. Research on effectiveness identified successful models. The State's goal is to establish IMPAC programs in every school and provide training and support.

During 1986-87, nine experimental satellite education programs in secondary schools were funded and distance learning policies were developed. Nineteen districts currently offer courses by satellite with funding assistance from IMPAC.

California

State position/unit: Yes (1982)
State plan: Yes (1986)
Key actors: Business community; legislators; State Advisory Committee; Chief State School Officer; SDE Staff
Funds available through the State for technology activities: State technology
Source of funding in most districts: Unknown
State training policies: Preservice (required)
State funding for technology training: Yes
Way most teachers receive training: Unknown
Most important State action: State level initiatives in software development, summer training institutes, and model schools
Major changes in past year: Large funding cuts by Governor
Barriers: Political consensus on definition of equity; State's ability to fund categorical programs; lack of software which "compels" use of technology

Legislation passed in 1982 and 1983 defined the State's role in educational technology and authorized several large grant programs. Educators and schools were encouraged to integrate technology in the curriculum. Funding was provided for matching grants to schools and districts," statewide software acquisition and development, and for the Technology in the Curriculum Projects, an initiative to match software and ITV programs with curriculum objectives. There were also funds for Summer Institutes and videocassette recorder (VCR) distribution. Teacher Education and Computer (TEC) Centers, first established in 1982, offered information and training to educators. Fifteen million dollars was allocated for California's technology efforts in 1984-85, $25.6 million in 1985-86, and about $25 million in 1986-87. The Governor cut the educational technology budget in half in 1987-88. Budget cuts eliminated the TEC Centers and the Summer Training Institutes.

Over $1 million supported the development of six educational software programs in mathematics, science, and history/social studies in 1986-87. Under the terms of the agreement, publishers are responsible for marketing costs and will retain copyright. California will receive royalties and discounts for the software. Although less money is available for technology, there is continued interest in supporting software development in partnership with other States or educational organizations.

State educational technology finding supports a model schools program in five sites. The goal is to study the use of technology by students over a 3 to 5 year period. Sites draw on a combination of State, Federal, and industry support and universities provide assistance with research and evaluation. Annual State funding for the program is contingent on the total funds for technology approved by the Governor.

Beginning July 1988, all teachers who apply for certification must meet new State requirements in computer-related coursework.

2-Contingent on the development of a local plan

Colorado

State position/unit: Yes (1982)
State plan: Being developed
Key actors: Legislators; local Boards of Education
Funds available through the State for technology activities: Federal
Source of funding in most districts: Mixed
State training policies: None (beginning to consider)
State funding for technology training: None
Way most teachers receive training: District
Most important State action: Creating staff positions in SDE; formation of telecommunications consortium
Next steps: Legislative action
Major changes in past year: None; funding remains a prime concern
Barriers: Funding; statewide direction (local control makes it difficult)

In Colorado, where there is a tradition of strong local control of education, State-level consultants provide guidelines and assistance to schools and districts. State technology activities are supported with Chapter 2 funds. Recently, a telecommunications consortium made up of educators, State staff, representatives from business, industry, and higher education was formed to address problems faced by small, isolated school districts.

Connecticut

State position/unit: Yes (1980)[28]
State plan: Being developed
Key actors: Business community; State Advisory Committee; Chief State School Officer; teacher organizations; parents; SDE consultants
Funds available through the State for technology activities: State technology (pending for 1987-88); State education
Source of funding in most districts: District
State training policies: Preservice/inservice (recommended)
State funding for technology training: None[29]
Way most teachers receive training: Regional center
Most important State actions: Grants; training; establishing regional service centers with software preview centers; statewide electronic network; telecommunications projects

[28] Consultant position was vacant from 1984 to 1987.
[29] Other State funds for professional development are available in Connecticut.

Major changes in past year: Advisory council formed to develop State plan and funding proposals

Barriers: No instructional standards for use of computers; no training requirements; incompatible systems in schools; strong local autonomy; no funds for hardware; inequities between districts

Following the recommendations of a Joint Committee on Educational Technology, 1985 legislation created the Telecommunications Incentives Grants Program for distance learning, staff development, and on-line databases. Although $500,000 was requested for 1986-87, only $85,000 was appropriated. The State planned to request the same amount for 1987-88. Other grants are available to schools to enhance instruction and staff development involving technology, but no funds for hardware are available from the State. A State technology consultant advises schools and districts about technology and encourages the inclusion of technology in grant proposals. Technology training is available through regional Institutes for Teaching and Learning, a $2.5 million staff development effort. Connecticut has established a statewide electronic network that disseminates information about technology.

Delaware

State position/unit: Yes (1983)

State plan: Yes (1983; being revised)

Key actors: Legislators; State Advisory Committee; State Department of Public Instruction

Funds available through the State for technology activities: State technology

Source of funding in most districts: District

State training policies: None[30]

State funding for technology training: Yes

Way most teachers receive training: District

Most important State action: Creation of unit in SDE; statewide computer network; establishing statewide technology council; training

Major changes in past year: None

Barriers: Funding for hardware/software; lack of quality software that relates to existing curricula; proof that there is a need for and value to using computers in the schools

Delaware has provided funding to school districts for computer education for 15 years. An electronic network, maintained by the State links school districts. The State has appropriated funds to all school districts on a per student basis since 1984 and districts must submit plans in order to receive State funds. A 1984 State plan emphasized computer literacy, computer science, administrative, and training needs, and gave some attention to other instructional applications of computers and other technology. A new plan is being reviewed.

Three centrally-located training laboratories, established in 1983, provided training on computer literacy; training has shifted to integration of technology into the curriculum. Districts can use State funds for training. Delaware also offers scholarships for training/retraining in computer science.

A study of the use of CAI systems for basic skills was conducted in 1987-88.

District of Columbia

State position/unit: Yes (1983)

State plan: Yes (1983)

Key actors: State Advisory Committee; Chief State School Officer; school board; city council

Funds available through the State for technology activities: State technology; Federal

Source of funding in most districts: Mixed

State training policies: Preservice (required); inservice (recommended)

State funding for technology training: Yes”

Way most teachers receive training: State/District

Most important State action: Board policy authorizing first Five-Year Plan (1983)

Next steps: Development of second Five-Year Plan

Barriers: Additional funding and training to improve scope of use

A Five-Year Plan specified certification and training requirements for educators, created a central training site, and set forth curriculum mandates for grades K-12. Funding for all technology-related instructional and administrative activities is included in the District of Columbia annual school budget. Yearly expenditures exceeded $3.3 million in 1986-87 and were about $3.5 million in 1987-88. Chapter 1 and Chapter 2 funds are used to provide additional computer laboratories in elementary and junior high schools. A second Five-Year Plan for computer education is in the final stages of development.

Florida

State position/unit: Yes (1981)

State plan: Yes (1987)

Key actors: Legislators; Chief State School Officer

Funds available through the State for technology activities: State education,[32] Federal

Source of funding in most districts: District

State training policies: Preservice/inservice (recommended)

[30] A certification program for computer science teachers is pending approval. Teachers are currently taking courses for certification.

[31] Funds for training in technology are Included in the overall budget for technology.

[32] The State provided funding for educational technology in 1983-84, but no funds have been allocated since.

State funding for technology training: Yes[33]
Way most teachers receive training: District
Most important State action: Computer literacy requirement for all students in grades 3, 5, 8, and 11
Next steps: Certifying teachers in computer education
Major changes in past year: None
Barriers: Funding; legislative support; coordination between universities, community colleges, and school districts

Legislation in 1981 stated that technology should be used to enhance the learning process and reduce administrative burdens on teachers. Attention to cost-effectiveness was emphasized. In 1983-84, a one-time $10 million appropriation was given to schools on a per student basis for hardware and software for mathematics and computer literacy. Several related programs in mathematics, science, and computer education for students and teachers were established[34] and $2 million in Federal funds were allocated for computers for vocational education schools. These programs and several additional projects have continued to receive funding, but for the past 3 years no State funds have been allocated for educational technology. Federal Job Training Partnership Act and Chapter 1 funds are used for technology. SDE proposed that the legislature provide $10 million in 1988-89 to assist districts with implementation.

The State supports a statewide electronic network, the Florida Information Resources Network. The Florida Center for Instructional Computing at the University of South Florida places software evaluations on the network. Florida also participates in SEED.

A 1987 plan calls for technology to support basic skills in grades K-8 and for computer-supported educational and career planning systems for secondary students. A new plan is being developed to direct funds toward a model schools project, statewide acquisition of hardware, and a comprehensive mathematics, science, and computer education program.

Georgia

State position/unit: Yes (1984)
State plan: Yes (1985)
Key actors: Business community; legislators; Governor; State Advisory Committee; Chief State School Officer
Funds available through the State for technology activities: State technology;[35] **Federal**
Source of funding in most districts: District
State training policies: None
State funding for technology training: No[36]
Way most teachers receive training: District
Most important State action: Formation of Georgia Technology Council; creation of Technology Coordinator position in all schools; State grants program; specification of technology standards and program components
Barriers: Competition for limited State funds

Georgia's Quality Basic Education Act became effective in 1985, establishing several grant programs and providing funds for instructional technology and the administrative networking of schools. In 1987, $500,000 was appropriated for hardware/software purchases and teacher training to use technology for recordkeeping and instructional management. Local districts must develop plans in order to receive grants. Other services (software evaluation and dissemination, training, and technical assistance) are provided by the State and regional education centers. Chapter 2 funds were used to pilot IBM's *Writing to Read* in five districts during 1987-88.

Member districts may purchase software cooperatively through the Georgia Software Consortium. The Consortium was initiated with State funding and is now supported by local districts. State staff select software and negotiate with publishers. Georgia also participates in SEED and distributes evaluations.

A pilot study is attempting to align Georgia's core curriculum for K-8 mathematics with standardized tests, State tests, software, video, and texts.

Hawaii

State position/unit: No
State plan: Yes (1980; revised 1987)
Key actors: Business community; legislators; Governor; State Advisory Committee; Chief State School Officer
Funds available through the State for technology activities: State technology; Federal
Source of funding in most districts: State
State training policies: Preservice/inservice (recommended)
State funding for technology training: Yes
Way most teachers receive training: District
Most important State action: Providing resources to implement State plan
Next steps: Development and expansion of plan
Major changes in past year: None

[33] Summer inservice institutes have made funds available for content area, non-credit training activities.
[34] 1) Post-Secondary Programs of Excellence in mathematics, science, and computer education for teacher training and cooperative activities between universities, colleges, businesses and school districts. 2) Two Regional Centers of Excellence in mathematics, science, and computer technology to develop instructional techniques, train teachers, and evaluate instructional materials. 3) Grants for summer camps for students and summer inservice programs for mathematics and science teachers.

[35] Funding for 1987-88. No funding was provided for educational technology in 1986-87.
[36] Staff development funds may be used for technology training.

Barriers: Time and additional resources to catch up to and maintain pace with new developments

Funds for technology are allocated on a per capita basis and distributed to all districts for computer literacy, CAI, computer-managed instruction, and computer-based information retrieval. Over $1 million was allocated in 1986-87 and $1.8 million in 1987-88. All schools can apply for Chapter 2 funds. In 1987, SDE developed a framework for continued planning and State activity.

About $150,000 was allocated to seven districts for inservice training activities in 1987-88. General staff development funds also are available to all districts. Some training via telecommunications is being initiated.

Software is evaluated through a Computer Review Center and Clearinghouse.

Idaho

State position/unit: Yes (1984)
State plan: Yes (1985)
Key actors: State Advisory Committee; Chief State School Officer
Funds available through the State for technology activities: State education; Federal
Source of funding in most districts: District
State training policies: None
State funding for technology training: None
Way most teachers receive training: District
Most important State action: Slow approach has allowed users to develop necessary comfort level
Next steps: Continue current efforts
Major changes in past year: Increased legislative interest in distance learning
Barriers: High costs; rapid change of technology

State funding for technology is available indirectly through general State aid. Districts may also use Chapter 2 funds. SDE and Boise State University support a distance learning mathematics class for rural classrooms. Teacher training in technology is provided through university preservice and inservice activities and SDE-sponsored workshops.

Illinois

State position/unit: No
State plan: Yes (1985)
Key actors: Legislators; Governor; business community; Chief State School Officer
Funds available through the State for technology activities: State technology; State education; Federal
Source of funding in most districts: State grants that may be used for technology
State training policies: None[37]
State funding for technology training: Yes
Way most teachers receive training: Regional centers
Most important State action: Creating computer consortia and incorporation into Educational Service Centers
Major changes in past year: None
Barriers: No particular barrier; remaining questions are not what can be done with technology, but what should be done

In 1985, the Illinois legislature incorporated 20 existing State-funded computer consortiums into 18 Educational Service Centers (ESCs). As part of an effort to aggregate services, ESCs are required to offer technology support to districts, developing budget requests based on local needs and priorities. In 1986-87, $8.5 million was appropriated for 18 ESCs and $8.16 million in 1987-88. A Math/Science Equipment and Materials Loan Program was initiated by the State in 1987 with a one-time $20 million appropriation.

Illinois does not provide direct support for distance learning but local districts may, and do, use State aid. An electronic network between SDE and regional centers is in place; some centers also have a network with local districts.

Training in technology is offered through ESCs. Staff development funds also are available. A software evaluation database is available to each ESC.

Indiana

State position/unit: Yes (1980)
State plan: Yes (1983)
Key actors: Legislators; Governor; Chief State School Officer; Consortium for Computer and High Technology Education
Funds available through the State for technology activities: State technology; Federal
Source of funding in most districts: Capital Improvement Fund[38]
State training policies: Preservice (recommended)
State funding for technology training: Yes
Way most teachers receive training: State
Most important State action: Funding training rather than hardware/software; funding demonstration projects; change in laws to allow purchase of hardware via Capital Improvement Fund; creation of low-interest loan program.
Major changes in past year: None
Barriers: Curriculum

In 1983 legislation created the Consortium for Computers and High Technology Education. The Consor-

[37]Institutions of higher education recommend training/courses in technology.

[38]A separate local tax levy funds buildings, replacements, and renovation. The second primary source of funding for technology at the district level is the School Technology Advancement Account, a State low-interest loan program.

tium developed a plan addressing training, research, and demonstration, but not curriculum. Over $5 million was appropriated for training and demonstration projects for 1985-87 and again for 1987-89. Funds for districts are also available through a Low Interest Loan Program, the State Capital Improvement Fund, and Federal Chapter 1, Chapter 2, and Title II programs.

The first round of State funding focused on teacher training. Initial efforts provided introductory level training (with substitutes) through nine training centers and more advanced training through local funding and colleges/universities. The centers were closed and training is now conducted at school sites by regional consultants. Indiana now funds some local programs and teacher fellowships.

With State funds, nine demonstration projects with a 2:1 ratio of students to computers were implemented in self-contained classrooms in 1985. Eight of the projects received sustaining levels of funding for a second year and competition was opened for additional sites. The next steps include replication,

Iowa

State position/unit: No[39]
State plan: No
Key actors: Intermediate service agencies
Funds available through the State for technology activities: State education; Federal
Source of funding in most districts: State grants that may be used for technology
State training policies: None
State funding for technology training: None
Way most teachers receive training: Regional centers
Most important State action: Start-up money for Instructional Software Clearinghouse
Major changes in past year: State program was eliminated and funding cut; responsibility now at local and regional level
Barriers: Completion of statewide electronic network

Legislation in 1987 contained a provision for checking wasteful proliferation of computers and mandated that plans be approved by the State before any local funds could be spent on technology. A State unit was created in 1973 and, with State coordination, 13 regional computer centers were established with local funds. These centers have been phased out and regional education units now provide consultant and support services to schools and districts. In 1987, the State technology unit was also eliminated. General State aid and Federal funds are used at the discretion of local districts.

In 1982,$100,000 from the legislature (to be paid back later) provided seed money for a software clearinghouse. Additional funds were appropriated in 1984 and 1985. The start-up money for the clearinghouse, which bought software at reduced rates and sold it to schools, was paid back and the clearinghouse functions were turned over to intermediate units,

With Iowa Public Television, SDE helped coordinate five distance learning projects using local funding and business support. Districts interest in a statewide electronic network that would use existing distance learning systems is under investigation.

Kansas

State position/unit: Yes (1984)
State plan: No
Key actors: Chief State School Officer
Funds available through the State for technology activities: State education; Federal
Source of funding in most districts: District
State training policies: Preservice (required); inservice (recommended)
State funding for technology training: None
Way most teachers receive training: District
Most important State action: Creating position in SDE
Major changes in past year: None
Barriers: Funding; perceptions of need

General State aid is available to districts for technology and Title II funds are available for training. Planning and curriculum development assistance is available as requested by the districts.

Kentucky

State position/unit: Yes (1984)
State plan: Being developed
Key actors: Business community; Governor; State Advisory Committee; Chief State School Officer; Chair, State Board of Education
Funds available through the State for technology activities: State technology; State education; Federal
Source of funding in most districts: Parent-Teacher Association funds
State training policies: Preservice (required); inservice (recommended)
State funding for technology training: None
Way most teachers receive training: State through district
Most important State action: Created computer specialist position and similar positions in special education in SDE
Next steps: Additional staffing and creation of State unit for instructional computing in SDE

[39] An educational technology unit in the State Department of Education was created in 1973 and abolished in 1987.

Major changes in past year: Governor's office worked with private vendor to create more involvement in educational technology; electronic network proposed

Barriers: Lack of funding to equalize districts; lack of funding for ongoing inservice training

In 1986, the legislature passed two grant programs to address educational priorities, particularly the Kentucky Essential Skills curriculum. Some projects receiving grants involve technology. Additional funding for educational technology is local or comes from Federal funds. In 1986-87, a statewide electronic network for administrative uses, the Kentucky Educational Networking System was proposed. The project will place a terminal on each teacher's desk at no cost to the districts.

Kentucky requires teachers to have at least one course in using technology for certification. Most inservice training is conducted by local colleges of education.

The Kentucky Network for Educational Telecommunications, a cooperative effort of the Kentucky Association of School Administrators, SDE, Kentucky Educational Television, and the Kentucky School Boards Association provides networking and information to subscribing educators and administrators.

Project Vision, a videodisc project in basic mathematics in grades K-2, was tested in eight sites and funded primarily through donations and private in-kind support. The program was designed with input from teachers and incorporates the Kentucky Essential Skills curriculum. Through an agreement with the vendor, hardware and software for the project are now available outside of Kentucky.

A task force is investigating potential for ITV and inservice programs. The State will install a satellite dish on every school building by 1988-89.

Louisiana

State position/unit: No

State plan: No

Key actors: Teacher organizations; district superintendents

Funds available through the State for technology activities: None

Source of funding in most districts: Chapter l/Chapter 2

State training policies: Preservice (required)

State funding for technology training: None

Way most teachers receive training: District

Major changes in past year: New Governor and superintendent in March 1988

Barriers: Funding

Federal Chapter 1 and Chapter 2 funds are the main source of funding for technology in Louisiana at the local level. No State funds are provided for technology, and State involvement is limited. SDE offers information and assistance to schools and conducts an annual survey of computer use. A half-unit course in computer literacy is required for high school graduation (a computer science or data processing course may be substituted). Certification requirements for computer literacy and computer science teachers have been established.

Maine

State position/unit: Yes (1979)[40]

State plan: Being developed

Key actors: Legislators; Governor; Chief State School Officer; Maine Computer Consortium; State computer consultant

Funds available through the State for technology activities: State education; Federal

Source of funding in most districts: Chapter 2

State training policies: None (being reviewed)

State funding for technology training: None[41]

Way most teachers receive training: District

Most important State action: High school proficiency requirement; creating half-time computer coordinator position; use of Chapter 2 funds for Computer Consortium

Next steps: Survey districts; develop State plan

Major changes in past year: High school proficiency requirement

Barriers: Lack of funds; proof of effectiveness; legislative support; local priorities

As part of a 1984 reform act, high school students in Maine are required to demonstrate proficiency in the use of computers. Local districts define proficiency and must submit a plan for State approval. No State funds are earmarked for technology and no other technology-related initiatives have been proposed at the State level. Maine's Innovative Grants program may award funds to programs with a technology component. Professional development funds are available for training in technology and the SDE staff provide training and assistance to educators, schools, and districts. Funding for the State's educational technology activities and for technology in most districts comes from Chapter 2 money.

New institutional relationships have been developed to facilitate the use of technology in Maine's schools. The Maine Computer Consortium was created in 1983 using Chapter 2 funds. The Consortium, which provides training, software review and preview services, and technical assistance to member districts has continued to receive Chapter 2 funding from the State, but most support comes from member districts. In 1986-87, with a $20,000 State Chapter 2 grant and in-kind gifts from Apple, the

[40] Half-time position.
[41] Staff development funds may be used for technology training.

Consortium created ME-Link, an electronic network. The network is available to any educator in the State with a modem. The Consortium received $5,000 in Chapter 2 funds in 1987-88 to publish descriptions of exemplary programs involving technology in the State's classrooms.

Maryland

State position/unit: Yes (1986)
State plan: Yes (1987)
Key actors: Business community; State Advisory Committee; Chief State School Officer; teacher organizations
Funds available through the State for technology activities: State education; Federal
Source of funding in most districts: Chapter 2
State training policies: None
State funding for technology training: Yes
Way most teachers receive training: District
Most important State action: Maryland Educational Technology Network
Major changes in past year: Development of State plan; alternative funding programs; partnerships with business and industry
Barriers: Determination of effectiveness; funding

The Maryland Education Technology Network (METN), a project to provide hardware, software, information, and staff support, is a joint effort of the State, districts, and vendors. The goal of METN is to deliver educational materials equitably to schools statewide. During 1985-86, IBM-networked computer laboratories were pilot tested in five schools and the project was evaluated. SDE assisted with training and coordination. METNs have been implemented in 31 school sites using grants from vendors, local funds, and State/local matching grants.

The Maryland Education Foundation (a private foundation) provided $100,000 for State/local matching grants for hardware in 1986-87. There are plans to expand METN, but no State funding has been allocated. Currently, METN is being upgraded to deliver software electronically and to connect sites with SDE.

The State allocated $59,000 to 24 school districts in 1988-89 for training to help teachers integrate technology into the curriculum.

Massachusetts

State position/unit: Yes (1987)[42]
State plan: Yes (1987)
Key actors: Legislators; State Advisory Committee; professional teacher organizations
Funds available through the State for technology activities: State technology; Federal
Source of funding in most districts: Varies by district
State training policies: None
State funding for technology training: Yes
Way most teachers receive training: Mixed
Most important State action: 1985 Act establishing the Educational Technology Trust Fund, subject to appropriations
Major changes in past year: Advisory Council has presented a State plan and requested increased funding
Barriers: Technology given a lower priority than some other issues

In 1985, State legislation created an Educational Technology Trust Fund to provide grants to local school districts for programs and model projects integrating technology into the classroom. An Educational Technology Council was established. The State allocated $500,000 for the grants program in 1986-87 and $600,000 in 1987-88. An Educational Technology Capital Improvements Grants program provided $1 million in 1987-88 to help districts purchase equipment. A State plan and a request for increased funding were presented to the Board of Education but no action has been taken.

The Commonwealth Inservice Institute, operated by the Massachusetts Department of Education, provides grants to districts for training teachers and administrators in the use of technology. In 1988, the SDE plans to assist schools in planning, acquiring, and training for the use of technology. Regional centers and a number of other consortia and organizations also provide assistance, support, and software preview services to schools and educators.

Four distance learning pilot projects, each connecting two sites, were funded in 1986-87 and 1987-88.

Michigan

State position/unit: Yes (1986)
State plan: Yes (1987)
Funds available through the State for technology activities: State technology; State education; Federal
Source of funding in most districts: District
State training policies: None
State funding for technology training: Yes
Way most teachers receive training: District
Most important State action: State plan; establishing regional technology centers; suggested curriculum guidelines
Next steps: Broaden scope
Major changes in past year: State plan, 1987
Barriers: Identification of common goals among various groups; coordination of grants

A 1983 educational reform report recommended that technology be integrated into instruction and educational

[42]In 1987, the Bureau of Educational Resources and Television was changed to the Bureau of Educational Technologies.

management. One-half year of “hands on” computer education was also recommended for high school graduation. As a result, a number of discretionary grants were awarded to schools and districts for technology projects. A State plan for technology, developed over 3 years, was approved in 1987. It calls for the State to provide technical and planning assistance to districts, assist in funding options for hardware and software, act as an information clearinghouse, conduct evaluations, and provide training. Over $1 million for Special Projects Discretionary Grants was appropriated by the State in 1986-87 and 1987-88. Funds for two-way interactive television and computer literacy/educational technology also were provided in 1987-88. Federal Chapter 1, Chapter 2, and Title II funds for technology are distributed on a joint basis.

Three regional centers provided software preview, information, and technology support services to districts. These services are now offered through the regional education service centers. An additional center for technology training was funded in 1987-88.

Minnesota

State position/unit: Yes (1979)
State plan: Yes (1985)[43]
Key actors: Business community; legislators; Governor; Chief State School Officer
Funds available through the State for technology activities: State technology; State education; Federal
Source of funding in most districts: State grants that may be used for technology and district funds
State training policies: Preservice (recommended)[44]
State funding for technology training: Yes
Way most teachers receive training: State/District
Most important State action: Training; planning; focus on learning rather than technology
Major changes in past year: Distance learning use by rural districts
Barriers: Questions about cost-effectiveness relative to other improvement strategies

State educational technology efforts began in the 1970s with the creation of the Minnesota Educational Computing Consortium (MECC) to provide computer services to schools through a time-sharing system, train teachers, conduct evaluations, and develop software. The 1983 legislation extended State efforts through funding to districts for technology planning, training, and software purchase. Technology demonstration sites were also supported and State funds were appropriated to MECC for software development. Over time, MECC has supported its activities by selling software outside of Minnesota and is now a separate nonprofit corporation.

At present, Minnesota’s strategy is to make the use of technology “invisible”--less separate from other educational initiatives and objectives—by encouraging the use of application software in subject areas. Minnesota has also supported distance learning to teach elective courses. Funding for model technology projects decreased from $5.3 million in 1983-85 and 1985-87 to $2.8 million in 1987-89. Instead, innovative projects involving technology are supported under State funds for instructional design. State funds for technology are available through general State aid and Federal dollars are used at local discretion. Sixty percent of all educational funding is provided by the State. Minnesota has continued to fund technology training at about $865,000 per year. An $8 million professional development program provides opportunities for teachers to learn how to use technology in instruction.

Mississippi

State position/unit: No
State plan: Being developed
Key actors: Chief State School Officer; local district administrators
Funds available through the State for technology activities: Federal
Source of funding in most districts: District
State training policies: None
State funding for technology training: None
Way most teachers receive training: District
Most important State action: Pilot project assessing use of distance delivery using TI-IN
Major changes in past year: A State plan will be developed
Barriers: Funding; training

State activities and funding for educational technology in Mississippi are limited and the SDE staff person responsible for technology has left and has not been replaced. The State evaluates administrative software and participates in SEED. Title II funds are being used for a distance learning pilot project in a rural school. The State superintendent has appointed a chairman and committee to begin work on a State plan for technology in the schools.

Missouri

State position/unit: No
State plan: No
Key actors: Business community; teacher organizations
Funds available through the State for technology activities: State education; Federal

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[43]Minnesota's 198 plan Information Technology Learner Outcomes focuses on enhancing learning using educational technology and lays out broad educational goals with suggested instructional approaches.

[44]Minnesota requires media teachers to demonstrate familiarity using technology in instruction at the preservice level and recommends that all preservice and inservice teachers take a computer-related course and/or show familiarity using technology in instruction.

Source of funding in most districts: Chapter 2
State training policies: None
State funding for technology training: Yes
Way most teachers receive training: District
Most important State action: Onetime allocation of $3 million in 1985-86
Next steps: Dissemination of information unsuccessful projects followed by incentives to adopt
Major changes in past year: None
Barriers: Diversity; funding; lack of training/commitment by school staffs

During 1985 -86,$2.5 million was provided by the Missouri legislature for hardware, software, and staff training. Most went to school **districts on a formula basis and** the rest was used for training provided by temporary State consultants.

No State funds have been appropriated specifically for technology since; however, $4 million for innovative and exemplary programs was provided in 1986-87. These funds may be used for training. In addition, State textbook funds may be used for software. Federal Chapter 1, Chapter 2, and Title II funds may be used by districts for technology at local discretion.

In 1987, the Missouri School Boards Association established the Educational Satellite Network (ESN) to provide interactive instructional programming, inservice education, and other programs. ESN owns and maintains all satellite receiving systems and schools pay for installation, local maintenance, and program guides. The State will approve curriculum and programs on the system and the President of the State Board of Education will serve on the ESN Board of Directors.

Montana

State position/unit: Yes (1981)
State plan: No
Key actors: Chief State School Officer; teacher organizations; parents
Funds available through the State for technology activities: Federal
Source of funding in most districts: Chapter 2
State training policies: Preservice (required); inservice (recommended)
State funding for technology training: None
Way most teachers receive training: District
Most important State action: Active support of SDE in assisting schools and educators
Major changes in past year: All State funding is frozen and local levies cannot pick up slack due to voted initiative
Barriers: Funding; training; resistance to change

There are no legislative mandates or State funds for technology in Montana. The Board of Public Education recommends that all students become computer literate and SDE provides training and assistance to schools and districts. Curriculum decisions are made locally and districts decide how to spend State general aid and Federal funds. Teachers are required to have familiarity using technology in instruction at the preservice level. The Board of Education has begun to study accreditation standards for schools, and technology is a major concern for all subject areas.

A National Science Foundation and Title 11 funded program, Project IMPACT (Integrating Mathematics Programs and Computer Technology) is operated through the Montana Council of Teachers of Mathematics, the University of Montana, Montana State University, and the Montana Office of Public Instruction. Mathematics teachers in grades 7 to 12 will receive training to integrate technology into instruction during 1988-89.

Nebraska

State position/unit: Yes (1985)
State plan: Yes (1986)
Key actors: Chief State School Officer; Educational Telecommunications Commission
Funds available through the State for technology activities: None
Source of funding in most districts: District
State training policies: None
State funding for technology training: None
Way most teachers receive training: Mixed
Most important State action: None
Next steps: Do a realistic long-term plan
Major changes in past year: None
Barriers: Funding; politics; vision/understanding

Legislation in 1984 created the Educational Technology Consortium which developed a set of recommendations for instructional technology in Nebraska. No funding was appropriated for implementation, however, and activity varies depending on local priorities. The State provides technical assistance and training on a limited basis.

Nevada

State position/unit: Yes (1985)
State plan: Yes (elementary 1986; secondary 1988)
Key actors: District computer coordinators
Funds available through the State for technology activities: State education; Federal
Source of funding in most districts: District
State training policies: Preservice/inservice (recommended)
State funding for technology training: None
Way most teachers receive training: For-credit course paid for by teacher

Most important State action: State funding for technology appropriated in 1985
Major changes in past year: None
Barriers: Continued State funding

In 1985, the legislature appropriated $10 million on a one-time basis for educational technology; $7 million was used for K-1 2 program improvement and $3 million was earmarked for vocational/occupational education. Additional discretionary funds were provided in 1985-86 and 1986-87 for overall program improvement but were not designated for technology. These State funds and Federal Chapter 1 and Chapter 2 funds are used at local discretion. Some Chapter 2 grants awarded by the State include a technology component. An elementary course of study was adopted which includes computer literacy and use. A secondary course of study with a computer component is being developed.

The State funded a distance learning pilot project within one district for 2 years. The project is now funded locally. There is concern that distance learning efforts are duplicated and a new task force will develop recommendations regarding educational telecommunications for the 1989 legislative session.

The State technology consultant provides assistance and training by request. Training grants are provided with Title II funds,

New Hampshire

State position/unit: No
State plan: Yes (1986)
Key actors: Business community; legislators; Governor; State Advisory Committee; Chief State School Officer
Funds available through the State for technology activities: State technology; Federal
Source of funding in most districts: State grants for technology
State training policies: None
State funding for technology training: Yes
Way most teachers receive training: District
Most important State action: Providing 1,950 teachers with computers for 3 years; interactive videodisc pilot project
Major changes in past year: Continued and increased funding for initiatives in place
Barriers: Changes in economy that may restrict spending

Under a 1985 Governor's Initiative Program, $5 million was awarded for education of the gifted and talented, computers for teachers, and technology in the classroom. An additional $2.5 million was appropriated for educational technology in 1987. With these funds, 1,950 teachers were provided with a computer for 3 years and offered training and networking assistance. In addition, grants were awarded to six teachers to develop model instructional lessons using videodisc. Empirical data was collected, but it is too early to assess effects on student outcomes. Other State grants are available for videodisc hardware, training, model projects, and distance learning. All grants require a training component. Federal Chapter 2 and Title 11 funds maybe used for technology-related activities at local discretion.

New Jersey

State position/unit: Yes (1983)
State plan: Yes (1986)
Key actors: Governor; State Advisory Committee; Chief State School Officer
Funds available through the State for technology activities: State technology; State education; Federal
Source of funding in most districts: District
State training policies: None
State funding for technology training: Yes
Way most teachers receive training: State
Most important State action: Creation of State technology unit; funding training centers; school improvement project for urban districts; implementing State plan; developing educational technology network
Next steps: Product development; training on integration of technology into classrooms
Major changes in past year: On a plateau now with no significant changes in sight
Barriers: Training; quantity of hardware still low in many districts

A State plan for educational technology was issued by SDE in 1986. Three regional training centers were established and provide free, ongoing services to educators. Each center consists of a training laboratory and a software/hardware library. A statewide telecommunications system, the Educational Technology Network, was created and provides free access to districts that have the right equipment. Technology is included as part of a comprehensive effort to improve educational services in three urban districts, called Operation School Renewal (OSR). Over $1 million supported these three programs in 1986-87 and $278,000 was provided in 1987-88. Funds for technology are also available through general State aid, Federal special education funding, and a portion of Chapter 1 funds.

A pilot project to transmit software electronically was implemented in Trenton in 1987 using OSR funds and vendor contributions. Other districts are expected to have similar capabilities soon. Three other pilot projects are looking at any changes in mathematics and writing skills of eighth grade students due to computer use and evaluating teachers' uses of computers. The technology component of OSR also is being evaluated and reports are pending. SDE has developed and used interactive videodisc technology and ITV for teacher support and training.

New Mexico

State position/unit: Yes (1980)[45]
State plan: No
Key actors: State Advisory Committee
Funds available through the State for technology activities: State education; Federal
Source of funding in most districts: State capital outlay funds
State training policies: None
State funding for technology training: None
Way most teachers receive training: District; for-credit course; teacher to teacher
Major changes in past year: State Board of Education approved guide for computer literacy in grades 1-8
Barriers: Training; research on effects of technology in instruction and how best to implement what exists in schools

In 1986, legislation mandated the inclusion of computer literacy and computer use in the instructional program for grades four through six, a computer literacy elective in grades seven through eight, and an elective course in computer science at the high school level. During 1985-86, over $1 million was appropriated to help schools purchase hardware and software. The funds were distributed on a competitive basis. Approximately half of the districts received funds; most received only partial funding for projects. The State has not provided additional funding for educational technology. Districts typically use State capital outlay funds for hardware and Federal funding is used for technology at local discretion. School districts provide for their own training needs.

New York

State position/unit: Yes (1982)
State plan: Yes (1985)[46]
Key actors: Legislators; Chief State School Officer; **teacher organizations**
Funds available through the State for technology activities: State technology; State education; Federal
Source of funding in most districts: State funds for technology received by all districts
State training policies: None
State funding for technology training: Yes
Most important State action: Creating technology unit in SDE; plan approved by Regents
Next steps: Remove regulatory and funding barriers; study potential policy barriers
Major changes in past year: A reconsideration of policy issues
Barriers: Regulations and funding mechanisms that make it difficult to use technology for instruction across institutional boundaries

The 1983 "Regents Action Plan to Improve Elementary and Secondary Education" required curriculum revisions and the integration of technology into all content areas, and initiated a range of State efforts to support the use of technology in education. The Center for Learning Technologies developed a plan of action in 1985 that included research and development (R&D), professional development, instructional materials, telecommunications, and technological integration. State funds support hardware and software purchase, the Technology Network Program (to link schools electronically), and 91 Teacher Resource and Computer Training Centers. About $36 million funded technology initiatives in 1986-87 and $41.2 million in 1987-88. In addition, the State provides partial funding for cooperative projects, many of which are technology related. Federal funds are used by districts and within the guidelines of specific programs, but specific figures are not available.

A Technology Planning Program for local districts was developed by the Center for Learning Technologies; replication is planned if the project is funded again. Training for educators is available through the Teacher Resource and Computer Centers.

Several projects targeted to specific populations, including the use of distance learning for rural schools, are also supported by the State. A proposal to study New York's educational policies is under consideration.

North Carolina

State position/unit: Yes (1984)
State plan: Yes (1983)[47]
Key actors: Legislators; State Advisory Committee; Chief State School Officer; district computer coordinators
Funds available through the State for technology activities: State technology; Federal
Source of funding in most districts: State technology funds received by all districts
State training policies: Preservice/inservice (recommended)
State funding for technology training: Yes
Way most teachers receive training: District
Most important State action: State plan; guidelines; funding for statewide computer education program

[45] A Computers in Education Committee has been established in the State Department of Education but, its Influence on State action has been minimal.
[46] New York's plan for educational technology is strategic, not operational. Some legislation proposed in the plan has been passed.

[47] North Carolina's State plan addresses the use of computers in schools

Next steps: Implementation of distance learning by satellite in all districts and 54 small schools

Major changes in past year: Computer legislation and funding completed; slowdown in growth and training expected; increased activity in telecommunications

Barriers: Time and funds for local school systems to implement State initiatives and directives

A State plan for computers in education was approved in 1983 and $28.5 million was appropriated for hardware, software, maintenance, and staff development over a 3-Year period (1984-87). The goal of State action was to provide at least 1 computer for every 50 students for at least 30 minutes of hands-on use per week. Districts were required to submit a plan for funds. In addition, Title 11 funds are used for innovative technology projects and to support the use of technology by underserved students. During 1986, SDE issued computer competencies for all students in K-12 and made recommendations on media center automation and computer facilities.

In 1986-87 a distance learning by satellite pilot project was undertaken using a Federal Title 11 grant. Following a positive evaluation, $3 million in State funds was allocated in 1987-88 to implement distance learning by satellite in 54 small, mostly rural high schools.

Three levels of technology competencies for educators have been defined by the State. A new title and increase in salary is awarded to teachers who reach an advanced level of training in technology and wish to take on a supervisory role. During 1985-87,$2 million was allocated to school districts on a per certified position basis for technology training. The State also appropriates $100 per teacher for staff development each year.

North Carolina participates in SEED.

North Dakota

State position/unit: No

State plan: Being developed

Key actors: Legislators; Governor; State Advisory Committee; Chief State School Officer

Funds available through the State for technology activities: State technology (1987-88); Federal

Source of funding in most districts: District

State training policies: None

State funding for technology training: None

Way most teachers receive training: For-credit course paid for by teacher

Most important State action: Appropriating funds for 1987-89

Next steps: Complete State plan; expand funding and implement plan

Major changes in past year: Reduced enrollment and financial resources and lack of upper level courses in certain areas may encourage greater use of technology, especially in rural schools

Barriers: Funding; attitude of administration; lack of training

Two pieces of legislation in 1987 provided funds for educational technology. No State funds were appropriated prior to this action. For 1987-89, a $500,000 appropriation enabled local school districts to purchase equipment and programming. The State allocated $100,000 to develop software on North Dakota history and geography with Broderbund Software and $50,000 for a foreign language distance learning program. Districts may use Chapter 2 funds for hardware. The State has provided funding to a public television station which provides some training in the use of instructional technology, primarily ITV. A State plan for technology is being developed.

Ohio

State position/unit: Yes (1984)

State plan: Being developed

Key actors: State Advisory Committee; Chief State School Officer; teacher organizations; other professional organizations

Funds available through the State for technology activities: State technology; State education; Federal

Source of funding in most districts: Chapter 2

State training policies: Preservice (required); inservice (recommended)

State funding for technology training: Yes

Way most teachers receive training: Regional centers

Most important State action: Educational Technology Center; curriculum and planning publications; Classroom of the Future project; annual statewide computer fair; ITV network which provides services through regional centers

Major changes in past year: Classroom of the Future projects expected to have a positive effect on State efforts

Barriers: Funding; unequal funding at local level; questions about extent of State role

The Educational Technology Center was established in 1984 to disseminate information, provide hardware and software preview, and offer technical assistance. Since 1979, the State has also supported the Ohio Education Computer Network, an effort to link all school districts for administrative purposes. SDE encourages the use of technology to promote learning skills and has developed guidelines in the area of industrial arts/technology education at the junior high and high school level, Approximately $4 million in Chapter 2 funds were used for instructional technology at the local level in 1986-87 and it is expected that a similar amount will be used in 1987-88.

In 1987-88, $200,000 was allocated to one school district to begin development of a curriculum that includes the use of technology. The district, which is working with local community colleges and businesses, has focused on training first and is seeking additional funds to continue. Ohio also has provided some funding (mostly Federal discretionary funds) for the Classroom of the Future, an effort to develop a model curriculum which includes technology and provides demonstration sites throughout the State. Recommendations will be produced in the summer of 1988 and additional State funds probably will be requested to implement demonstration projects,

Ohio requires preservice familiarity with the use of computers in instruction for certification. Inservice training is primarily the responsibility of districts and the ITV network. State funds for inservice training are available through a professional development program and categorical funds from lottery proceeds may be used for technology training. Federal funds are available through Title II and Chapter 2. The State has allocated $150,000 for planning for a Teacher Technology Center.

Oklahoma

State position/unit: Yes
State plan: No
Key actors: Business community; legislators; Chief State School Officer
Funds available through the State for technology activities: State technology; Federal
Source of funding in most districts: State grants for technology to a limited number of schools or districts
State training policies: Preservice (required)[48]
State funding for technology training: None
Most important State action: Satellite instruction regulations; establishing certificate of endorsement in computer science; State grants for technology
Next steps: Develop State plan
Major changes in past year: Decreased funding for education due to crises in oil and agriculture industries
Barriers: Funding; awareness, understanding, and support of decisionmakers

Since 1983, Oklahoma has funded a competitive technology grant program for school districts for equipment, software, and for administrative support for instructional programs. The State appropriated $1,5 million in 1986-87 and $1.9 million in 1987-88, Additionally, $50,000 was granted to Stillwater Public Schools for a PLATO-WICAT Computer Program in 1986-87. Computer science is a recommended elective for students preparing for admission to Oklahoma colleges and universities and schools are encouraged to use technology in ways to help meet the needs of students and faculty. A curriculum guide and recommendations for keyboarding have been developed.

The State supports a variety of distance learning and rural education activities: $330,000 for competitive Rural Technology Education Grants for Satellite Instruction in 1986-87 and again in 1987-88; $185,000 for Telecommunications in Education Grants; and a $212,000 grant to Oklahoma State University for satellite instruction course development in 1987-88, including a German-by-Satellite course. In 1987, the State Board of Education adopted regulations governing satellite instruction.

Computer-related courses at the preservice level are required for some teachers. The State provides no funding for training but offers workshops on site and through the SDE Computer Laboratory. SDE also maintains a software preview library and provides information and technical assistance to educators.

Oregon

State position/unit: Yes (1960s)
State plan: No
Key actors: Business community; Chief State School Officer
Funds available through the State for technology activities: State technology (1986-87); State education; Federal
Source of funding in most districts: Chapter 2
State training policies: None
State funding for technology training: Yes[49]
Way most teachers receive training: District
Most important State action: Providing curriculum materials for video (for over 20 years) and for computers (over 5 years)
Major changes in past year: Large decrease in State support for technology instructional materials
Barriers: State technology funding has been reduced each year since 1978

Oregon has supported instructional video since the 1960s. In the early 1980s, State and Federal funds helped to establish the Oregon Educational Computer Consortium (OECC). With dues from districts, OECC hired a staff person within SDE. In 1985-86, $25,000 in State funds was provided to support the Consortium. In 1986-87, $23,500 was provided to assist in a contract for software. No State funds were provided in 1987-88. General State aid and Federal funding may be used for technology at local discretion. A State plan was drafted but was not implemented.

Training, software preview, and technical assistance are provided to districts through OECC. The State also sup-

[48]Preservice coursework in computer literacy is required in Oklahoma for early childhood and elementary certification. At the secondary level, computer-related courses are required for teachers of business, mathematics, computer science, and for media/library specialist certification.

[49]Oregon provides funding for technology training indirectly through support for Oregon Public Broadcasting and the Oregon Educational Computer Consortium. Both provide teacher development activities.

ports Oregon Public Broadcasting which provides some staff development to teachers. Training is coordinated at the district level.

Pennsylvania

State position/unit: No
State plan: No[50]
Key actors: Legislators; Governor; State Advisory Committee; Chief State School Officer
Funds available through the State for technology activities: State technology; State education; Federal
Source of funding in most districts: Chapter 2
State training policies: Preservice (required); inservice (recommended informally)
State funding for technology training: Yes
Way most teachers receive training: District
Most important State action: Focusing Chapter 2 funds on technology; providing funding for training through regional centers and grants to schools; creating an electronic network; establishing a program to provide for joint purchase of computers by schools
Next steps: Establishing computer science certification
Major changes in past year: State funding requested for the Pennsylvania Higher Education Assistance Agency, a public corporation, and for the Science Teacher Education Program
Barriers: Diversity of districts; keeping up with changing technology

State Chapter 2 allocations have been used for competitive grants for technology and for inservice training, including PENN* LINK, an electronic network that is planned to link all schools and LIN-TEL, a statewide electronic network for libraries. Districts also use Chapter 2 funds for technology: in 1986-87, 29 percent of local Chapter 2 funds were used for computer hardware. Federal vocational education, special education, and Title 11 funds are also used for educational technology by the State and districts. In response to unequal distribution of computers, the State targeted Chapter 2 funds to rural districts in 1987-88.

Technology training and support services are provided by 15 Regional Computer Resource Centers (RCRC). The RCRCs are located at colleges, universities, and intermediate units and are administered by the Pennsylvania Higher Education Assistance Agency (PHEAA), a public corporation which receives State funding. PHEAA also administers technology grants to schools and districts, in addition to the grants awarded at the State level. Over $5 million was provided by the State in 1986-87 and again in 1987-88 for the educational technology programs administered by PHEAA and for other State initiatives, including a program which provides for joint purchasing of computers by schools. In 1986, the legislature approved a line item in the State budget for a videodisc database of school library holdings. In addition, $27 million in State funds were distributed to districts for 1984-87 to update vocational/technical programs in the State.

The use of computers to support the learning process is encouraged through the State's "Goals of Quality Education," New regulations require that computer science be offered to all secondary students. Teacher certification in computer science is being considered.

Rhode Island

State position/unit: No
State plan: No
Funds available through the State for technology activities: State education
Source of funding in most districts: District; Chapter 1; Title 11
State training policies: None
State funding for technology training: None[51]
Way most teachers receive training: Unknown
Major changes in past year: Planning initiative and considering creating technology centers
Barriers: No State level staff person

A half-unit computer literacy requirement for high school students was established in 1983. Over a 3-year period (1983-86), $4 million was appropriated for educational technology: $1 million was allocated for vocational facilities and $3 million for elementary and secondary schools. Districts are required to repay 40 percent of the funds over a 5-year period. The State completed a $300,000 inservice education program in 1986 which provided training for 5,000-6,000 of the State's 8,000 teachers. Teachers now may receive inservice training in technology under the Rhode Island School Staff Institute. A State initiative in educational technology is in the planning stages,

South Carolina

State position/unit: Yes (1983)[52]
State plan: No
Key actors: Legislators; Chief State School Officer
Funds available through the State for technology activities: State technology
Source of funding in most districts: State grants for technology

[50] There is no State plan for educational technology in Pennsylvania, A model technology utilization plan is being developed for special education and the State has a 3-year plan to link all schools in the State electronically.

[51] Professional development funds may be used for technology training.

[52] In 1983 an existing Office of Instructional Television was renamed the Office of Instructional Technology. South Carolina is revolved in a number of activities relating to instructional television.

State training policies: Preservice (required for business education)

State funding for technology training: Yes

Way most teachers receive training: For-credit course paid for by teacher

Most important State action: Pathways Project to reduce teacher paperwork; creation of State instructional technology unit; participation in curriculum mapping project through SEED[53]

Major changes in past year: None

Barriers: Need for more hardware and software; insufficient opportunity to preview software; training; questions about relating technology to the curriculum and teaching

Legislation enacted in 1984 established the Pathways Project, an effort to reduce teacher paperwork and create an electronic network for administrative uses. The project received $5.4 million in 1986-87. Approximately $300,000 was provided to districts for computer education courses over the past 3 years. Funds are allocated to provide at least one course per district and training is primarily a district responsibility. Inservice computer courses can be applied to renewal of certification in all fields.

The State publishes a recommended list of software for basic skills instruction in language arts, mathematics, and science, and operates six basic skills software regional laboratories. Staff development programs are broadcast over the South Carolina Educational Television Network. South Carolina participates in SEED.

South Dakota

State position/unit: Yes (1982)[54]

State plan: No

Key actors: State Advisory Committee; Chief State School Officer; local districts

Funds available through the State for technology activities: State education; Federal

Source of funding in most districts: District; Chapter 2

State training policies: Preservice/inservice (informally recommended)

State funding for technology training: None

Way **most** teachers **receive training: Mixed**

Most important State action: Creating technology position in SDE; creating statewide consortium

Next steps: Establish a permanent funding base for the technology consortium

Major changes in past year: None; hope that distance learning projects will generate more interest

Barriers: Funding; local leadership; training

A State position for educational technology was created in 1982 and a 5-year plan (1982-86) was developed. In 1985, a statewide educational technology consortium (TIE) was established with State support. TIE is funded by districts, which may use general State aid and Federal funds for membership or other technology-related activities.

South Dakota requires a half credit of computer studies, a hands-on course, for high school graduation. The development of computer-related skills (keyboarding, CAI, integrated tool software, and programming) is encouraged at all grade levels.

Three schools were selected by the State for distance learning pilot sites using the TI-IN Network in 1986.

Tennessee

State position/unit: Yes (1984)

State plan: Yes (1984)

Key actors: Legislators; Governor; State Advisory Committee

Funds available through the State for technology activities: Federal

Source of finding in most districts: Chapter 2

State training policies: Preservice (required)

State funding for technology training: None

Way most teachers receive training: State

Most important State action: Implementation of Comprehensive Education Reform Act

Major changes in past year: None

Barriers: Availability of additional funding

A mandate requiring computer literacy instruction for all seventh and eighth grade students was approved in 1983 and one-time funding of $9 million was provided to districts for hardware. Under the mandate, all students receive 15 computer literacy lessons in the seventh and eighth grade. Each instructor received an initial 5 days of training. Suggested curriculum guides have been developed to encourage the use of technology throughout the K-6 curriculum and to encourage computer science at the secondary level.

No State funds currently are available for educational technology. The State set aside $25,000 in Chapter 2 funds for a technology conference (1986-88) and $10,000 in Title 11 funds for technology in education. Tennessee continues to train teachers for the required computer literacy instruction and provides inservice training and technical assistance to other educators.

Texas

State position/unit: Yes (1983)

State plan: Being developed

[53] The SEED curriculum mapping project is in the planning stages. For more Information, contact the Southeastern Educational Improvement Laboratory,.

[54] A State-level educational technology position was created in 1982 in South Dakota. In 1985, responsibility for implementation and support was transferred to a statewide educational technology consortium (TIE). An assistant State superintendent maintains administrative responsibility for educational technology

Key actors: Legislators; State Advisory Committee; Chief State School Officer; professional associations
Funds available through the State for technology activities: State technology; Federal
Source of funding inmost districts: District
State training policies: Preservice (required); inservice (recommended)
State funding for technology training: None[55]
Way most teachers receive training: District
Most important State action: Computer literacy requirement for seventh or eighth grade and computer course requirement for advanced high school diploma; distance learning courses; electronic network
Next steps: Elementary computing guidelines; State plan; further implementation of distance learning and electronic network; further research and demonstration
Major changes in past year: State plan being developed
Barriers: No State plan; training; funding (for R&D, training, and equipment)

Legislation in 1981 requires that all students in Texas take at least one semester in computer literacy in seventh or eighth grade (beginning in 1985-86). The required course specifies applications, awareness, and programming. All districts are required to teach computer competencies, including keyboarding, in the elementary schools beginning in 1987. Guidelines are being developed. Texas also awards an advanced high school diploma which includes courses in computing.

The State has not funded local implementation efforts, but has funded several pilot projects with State and Federal dollars. In 1986-87 the State provided on-line expenses to 14 school districts to study their use of electronic communications. Minimal on-line expenses and money for software were provided to two model districts to study the potential of a statewide electronic network. In addition, Chapter 2 discretionary funds were used for 10 pilot districts to study the use of technology for basic skills instruction in 1986-87 and for 8 more projects in 1987-88.

Preservice teachers are required to take a computer course or demonstrate proficiency using computers in instruction. The State's long-term strategy for both preservice and inservice involves moving training for technology into universities and regional centers. Currently, the State technology unit initiates training efforts, provides technical and curriculum assistance, and is involved in long-range planning.

Utah

State position/unit: Yes (1985)
State plan: Being developed
Key actors: Business; legislators; Governor; State Advisory Committee; Chief State School Officer; parents; State staff
Funds available through the State for technology activities: State education; Federal
Source of funding in most districts: State grants that may be used for technology
State training policies: Preservice/inservice (required)
State funding for technology training: None (pending study)
Way most teachers receive training: District
Most important State Action: Educational Technology Study conducted in conjunction with IBM
Major changes in past year: Positive–completion and implementation of study
Barriers: Funding

Core curriculum standards for information technology are in place in Utah for grades K-12. These standards may be taught either by "infusing" them into other areas of the curriculum or in a specific course. An "Application Transfer Study," conducted in conjunction with IBM, was completed in 1987. The study assessed the current status of educational technology in Utah and made recommendations for future directions. No State funding is provided specifically for educational technology, but a recommendation is pending for the 1988 legislative session. State productivity grants have been used for technology by local districts. Federal funds are used to support the Information Technology Demonstration Center which serves as a clearinghouse for State efforts. The center also works with regional education service centers.

Teachers at the preservice and inservice level are required to take technology courses or demonstrate familiarity using technology in instruction. No State funds are provided for technology training, but a recommendation is under consideration.

In 1985, the development of a distance learning accelerated pilot project to teach Spanish was funded by the State with support from IBM and Bonneville International Corp., a private satellite company. The course is now available to schools in other States.

Vermont

State position/unit: Yes (1987)
State plan: Being developed
Key actors: Legislators; Chief State School Officer; teachers; parents; superintendents
Funds available through the State for technology activities: Federal
Source of funding in most districts: District
State training policies: None[56]

[55] The State provides additional funds to school districts to use in placing teachers on a career ladder. Technology workshops and courses may be applied toward credit *for the* career ladder.

[56] A pending State plan will recommend that all teachers demonstrate competency in using technology in instruction by 1990.

State funding for technology training: None
Way most teachers receive training: For-credit course paid for by teacher
Most important State action: Flexibility at local level
Major changes in past year: Creation opposition in SDE
Barriers: Funding

Vermont provides no funding for educational technology and only limited technical assistance and support. Federal funds are used for technology if proposals from districts include technology. Suggested curriculum guidelines have been developed and the State uses the term "technology capable" to encourage teachers and students to use technology as tools.

A technology staff position was established in 1987 and a State plan is being developed by SDE. The plan will encourage the implementation of a range of technologies in the early grades.

Virginia

State position/unit: Yes (1987)[57]
State plan: Being developed
Key actors: Business community; legislators; Governor; State Board of Education
Funds available through the State for technology activities: State technology; Federal
Source of funding in most districts: Unknown
State training policies: Inservice (recommended)
State funding for technology training: None
Way most teachers receive training: District
Most important State action: Governor's Commission issued Plan *for Action*
Next steps: Get legislative support; develop 5-year plan; implement plan
Major changes in past year: Potential legislation; development of plan; interest of Governor and some legislators
Barriers: Cost and rapid obsolescence of equipment; awareness of value among top educators; mobilize teachers to use technology over the long-term; stable funding commitment

All Virginia high school graduates must demonstrate computer competency. The State provides a training laboratory, information, and technical assistance to educators. An "electronic classroom," offering advanced courses and Latin instruction to some schools through the public broadcasting network in Virginia, was established in 1985 to address educational disparities across the State. A second electronic classroom was implemented in 1987 and half of Virginia schools have been involved. State costs for the electronic classrooms were $275,000 in 1986-87 and $600,000 in 1987-88. The State hopes to implement additional sites and plans to transmit courses using a combination of public television and satellite technology. No additional State funds are currently provided for educational technology. Federal funds may be awarded through grants for technology-related projects. Over $65,000 in Federal funds was approved for technology-based projects in 1987-88.

The Governor's Commission on Excellence in Education has issued a plan that includes a section about the use of technology. An Assistant Superintendent for Instructional Technology was created in 1987 and a State plan for educational technology is being developed. Over $20 million has been requested in the legislature for electronic classrooms, an electronic network, and computer purchases to address disparities in distribution of technology across the State. Training is included in the request. This is the first time a budget of this type has been proposed in Virginia.

A 2-year demonstration project, funded by the Potomac Edison Co., in cooperation with SDE in 1987, has 10 networked classrooms for mathematics and science. Proposals for evaluation are being developed.[58]

[57] A Department of Media and Technology has offered services to Virginia schools for several years under different departments within the State Department of Education. In August 1987, an Assistant Superintendent for Instructional Technology was hired, moving the department to division status.

[58] Potomac Edison is also supporting projects in West Virginia and Maryland.

Washington

State position/unit: Yes (1983)
State plan: Being developed
Key actors: Business community; legislators; Chief State School Officer; teacher organizations
Funds available through the State for technology activities: State technology; Federal
Source of funding in most districts: District
State training policies: Preservice (required)
State funding for technology training: Yes
Way most teachers receive training: Regional centers
Most important State action: Established Educational Technology Center Program and provided continued funding
Next steps: Collaboration between education, business, and industry
Major changes in past year: Telecommunications legislation passed in 1987; anticipated to have major impact
Barriers: Funding; release time for training; lack of coordination of resources between districts; lack of high-quality software; difficulty matching software with student learning objectives

A network of Educational Technology Centers was established through legislation in 1983. The centers provide inservice classes and workshops, technical assistance, software/hardware preview, and curriculum development assistance. The program is administered through the Superintendent of Public Instruction and currently has an operating budget of $2.3 million per year. Staff development grants are also available on a competitive basis to school districts. No other State or Federal funds are currently earmarked for technology. State grants for school improvement and research were used for some technology-related projects from 1985-87, but this program was not refunded. Federal Chapter 1 and Chapter 2 may be used for technology by local districts.

Preservice teachers are required to have familiarity with technology use in instruction, and high schools are required to offer computer-related courses. The State does not evaluate software, but has developed suggested curriculum guidelines to help educators match software to defined student outcomes.

An act passed in 1987 required SDE and the Higher Education Coordinating Board to develop a plan for a statewide telecommunications network. The plan will be submitted by the 1989 session. A separate proposal was submitted to the legislature which requested over $2 million for a number of initiatives, including technology project development, more staff for the Educational Technology Centers, grants for demonstration sites, and dissemination of information. The proposal was initiated through a cooperative effort between educators; business and industry, and the State superintendent.

West Virginia

State position/unit: Yes (1984)
State plan: No
Key actors: Business community; legislators; State Advisory Committee; SDE
Funds available through the State for technology activities: State technology;[59] State education; Federal
Source of funding in most districts: State grants that may be used for technology
State training policies: Preservice (required for certain areas); inservice (recommended)
State funding for technology training: None[60]
Way most teachers receive training: State
Most important State action: Providing some direction and funding
Next steps: Implement more laboratories and evaluate the use and place of technology within the curriculum; support development and use of instructional management software
Major changes in past year: Two studies being conducted by commissions on finance and education which may lead to more funding
Barriers: Funding; training; time to implement

Following a plan formulated in 1982-83, a statewide electronic network was installed in local school districts in 1984. The project was supported by the State with assistance from the Appalachian Regional Commission and the Federal Job Training Partnership Act. Computer laboratories were first implemented in high schools and are now being put into junior high schools. Training is provided at schools, through summer institutes, and occasionally via the electronic network. Originally intended for administrative and teacher use, the laboratories are now also used for instruction. In 1986-87, $200,000 was provided for laboratories and to cover the operational costs for toll-free access to the network by schools. Funding for 1987-88 is uncertain due to State budget cuts. School districts may also use grants for professional development, general State aid, and Federal funds for technology-related activities.

The State is evaluating distance learning projects to assess costs and educational outcomes.

Statewide learning outcomes for specific curriculum areas have been developed. Proficiency using technology to solve problems and enhance job skills is included in the learning outcomes for vocational education (word processing, spreadsheets, database management, and telecommunications). A 6-week pilot project supported jointly by the State, the U.S. Department of Labor, and IBM used computers and hands-on activities to provide practice in basic skills, career exploration, and improve students' attitudes toward school.

Wisconsin

State position/unit: Yes (1983)
State plan: Yes (1987)
Key actors: Legislators; State Advisory Committee; Chief State School Officer
Funds available through the State for technology activities: State education; Federal
Source of funding in most districts: District
State Training Policies: Preservice (required); inservice (recommended)
State funding for technology training: None
Way most teachers receive training: Regional centers
Most important State action: Establishing State educational standards; publishing series of curriculum guides
Next steps: Assist districts in planning and implementation; continued staff development
Major changes in past year: New standards have increased interest in using technology for instruction
Barriers: Reluctance to change and "fear" of technology; funding; local priorities and understanding

Reform legislation passed in 1986 resulted in State standards for curriculum and professional development.

[59] State funding for technology is pending for 1987-88.
[60] Professional development funds may be used for technology training.

A series of curriculum guides were published requiring changes in both the content and delivery of instruction. Technology is seen as an important component of school improvement and the State encourages local districts to integrate technology into the new curriculum. Local school boards are required to develop curriculum plans that specify objectives, course content, resources, and assessment. No State funds are provided specifically for technology or technology training. However, Wisconsin provides half of the funding for education statewide which may be used for technology at local discretion.

Twelve regional agencies, forming the Wisconsin Instructional Computing Consortium, provide educational technology services to members (such as training and technical assistance). State staff provide leadership and consultation to the regional units and districts. The State recognizes a need for additional training to integrate technology more fully into the curriculum. Beginning in 1988, the State will work with districts that are not complying with State standards, including those that are not using technology.

Wyoming

State position/unit: Yes (1985)
State plan: No
Key actors: District curriculum committees
Funds available through the State for technology activities: State education; Federal
Source of funding in most districts: District
State training policies: Preservice (required); inservice (recommended)
State funding for technology training: None
Way most teachers receive training: District
Most important State action: Technology position in SDE; center to provide software preview/evaluation
Major changes in past year: Oil prices have negatively affected school funds
Barriers: Isolation/small size of most schools in State; questions about how to encourage teachers to incorporate technology in instruction, especially in high schools

Almost all State funding for education in Wyoming goes directly to districts. Chapter 2 is used heavily by districts for technology, but districts are discouraged from using Chapter 1 funds for technology because it is difficult to monitor use. Districts are encouraged to develop their own plans for educational technology and a State consultant is available to offer assistance. The State maintains the Center for Educational Technology, where software is available for preview. The center also publishes software reviews. Preservice teachers are required to demonstrate familiarity using technology in instruction. A State policy on distance learning was recently adopted and a project is expected to be implemented in one district in 1988-89.

Appendix B

Characteristics Considered in Evaluating Educational Software[1]

Instructional Quality

General

- Program is useful in a school-based, instructional setting (i.e., in a classroom, computer laboratory, media center, or school library).
- Program avoids potentially controversial, nonstandard teaching methodologies.
- Program allows completion of a lesson in one class period (approximately 30 minutes).
- Instruction is integrated with previous student experience.
- Program is likely to save time for the student when compared to other means of presenting this topic.
- Program is likely to save time for the teacher when compared to other means of presenting this topic.
- An on-disk tutorial concerning the program's command structure is provided when appropriate (e.g., for a word processing program).

Content

- Content is appropriate for intended student population.
- Content is accurate.
- Content is current.
- Content breadth is reasonable (does not focus on too few or too many different concepts or content topics within one session).
- The processes and information learned are useful in domains other than the subject area of the program.
- Content is free of grammar, spelling, punctuation, and usage errors.
- Content is free of any bias or stereotyping.
- Content supports the school curriculum.
- Content is relevant to the subject field.
- Definitions are provided when necessary.
- There is continuity between the information presented and prerequisite skills required.
- Content avoids taking a side on potentially controversial moral or social issues.
- There is a need for better than the standard treatment of this topic in the curriculum.

Appropriateness

- Application is well suited to computer use.
- The pedagogic approach used is superior to what is available elsewhere.
- Readability level is appropriate for the intended student population.
- Tone of address is appropriate for the intended student population.
- The means of response (e.g., single keystroke, manipulating graphics) is appropriate to the intended student population.
- Prerequisite skills required are appropriate for the intended student population.
- Time required for use by a typical student does not exceed the attention span of that student.
- Multiple levels of instruction *are* available.
- Difficulty levels are based on discernible logic (e.g., reading ability, complexity of problems).
- Sufficient exposure and practice are provided to master skills.
- Sufficient information is presented for intended learning to occur.

Questioning Techniques

- Questions are appropriate to the content and effectively measure student mastery of the content.
- Questions incorrectly answered can be repeated later in the lesson/exercise.
- The number of trials are reasonable and appropriate (e.g., student receives the correct answer after no more than three or four trials, and after at least two trials).
- Calculation can be accomplished easily on-screen when appropriate.

Approach/Motivation

- Approach is appropriate for the intended student population.
- Format is varied.

[1] Based on items used by 36 public private, and governmental software evaluation agencies, and additional items considered important by selected teachers, software publishers, university professors, and private consultants. Many of the educational software experts consulted in the compiling of this list felt that subject-specific and population-specific characteristics would have to be considered for a thorough evaluation. See Ellen Bialo and Jay Sivin, "An Analysis of the Scope and Quality of the Current Supply of Educational Software and of the Available Sources of Information on Educational Software," OTA contract report, Sept. 30, 1987.

- Overall tenor of interaction is helpful.
- Student is an active participant in the learning process.

Evaluator's Field Test Results

- Student understands the on-screen presentation, and can proceed without confusion or frustration.
- Student enjoys using the program.
- Student retains a positive attitude about using the program.
- Student retains the desire to use the program again, or to pursue the topic in other ways.
- Program involves students in competition in a positive way.
- Program fosters cooperation among students.

Creativity

- Program challenges and stimulates creativity.
- Pedagogy is innovative.
- Program allows the student as many decisions as possible.
- Program provides opportunities to answer open-ended questions and provides evaluative criteria to assess responses.
- Program demonstrates a creative way of using knowledge.
- Program challenges the student to alter an underlying model, or design an alternative model.

Learner Control

- Learner can alter program sequence and pace.
- Learner can review instructions and previous frames.
- Learner can end activity any time and return to main menu.
- Learner can enter program at different points.
- Learner can stop in the midst of an activity, and at a later session begin at that stopping point with the previous record of progress intact.
- Help is available at likely points of need.

Learning Objectives, Goals, and Outcomes

- Learner objectives are stated and purpose is well defined.
- Steps are taken to make learning generalizable to other situations.
- For programs requiring use over several days, learning outcomes are worth the time invested.

Feedback

- Feedback is positive.
- Feedback is appropriate to the intended student population and does not threaten or inadvertently reward incorrect responses.
- Feedback is relevant to student responses.
- Feedback is timely.
- Feedback is informative.
- Feedback is corrective when appropriate.
- Feedback remediates and/or explains when appropriate.
- Feedback employs a variety of responses to student input, and avoids being boring or unnecessarily detailed.
- Feedback remains on the screen for an appropriate amount of time.
- Branching is used effectively to remediate.
- Program uses branching to automatically adjust difficulty levels or sequence according to student performance.

Simulations

- Simulation model is valid and neither too complex nor too simple for intended student population.
- Variables used in the simulation are the most relevant.
- Variables in the simulation interact and produce results approximately as they would in real life.
- Assumptions are adequately identified.
- Program simulates activities that can be too difficult, dangerous, or expensive to demonstrate in reality.
- The time needed to complete both a step and the entire simulation is reasonable and effective.
- Encourages decisionmaking or calculation rather than guessing.

Teacher Modifiability

- Teacher can easily change or add content.
- Teacher can easily regulate parameters (e. g., number of problems, rate of presentation, percentage correct needed for mastery) for each class using the program,
- Teacher can easily regulate parameters (e. g., number of problems, rate of presentation, percentage correct needed for mastery) for each student.
- Parameter set-ups can be bypassed (e. g., default settings are available).

Evaluation and Recordkeeping

- Program provides an adequate means of evaluating student mastery of the content.
- If tests are included, criteria for success are appropriate for the ability/skills of the intended student population.
- [f tests are included, content accurately reflects the material presented.
- Scorekeeping and performance reports are provided for the student when appropriate (e.g., summary of problems correct/number attempted, running point totals).
- Useful information about student performance is stored for future retrieval.
- Useful diagnostic pre-test or placement test is provided, where appropriate.
- Useful diagnostic or prescriptive analysis of student performance is available to the teacher, when appropriate.
- Student performance information is easily accessible to the teacher.
- Management system includes adequate security.
- Program allows printout and screen display of student records.
- Program can hold multiple performance records of a single class (e.g., 35 to 50 students).
- Program can hold multiple performance records of several classes (e.g., up to 5 classes) arranged by class.

Documentation and Support Materials

- Quality of packaging is durable and appropriate for student use (e.g., not too large to be used at a computer station).
- Student, parent, or teacher guides and materials are clearly identified as such.
- Technical and operational explanations for implementation are clear and complete.
- If appropriate, "quick start-up" section is included.
- Useful reproducible student worksheets are provided.
- Other valuable support materials are provided (e.g., wall charts).
- Sample screen-by-screen printouts of the program are provided.
- Teacher support materials can be separated from student materials.
- Useful suggestions are provided for introductory classroom activities.
- Useful suggestions are provided for classroom activities during the use of the program, where necessary or helpful.
- Useful suggestions are provided for followup activities.
- Useful suggestions are given for classroom logistics in a variety of hardware situations (e.g., single or multiple machines) and student groupings.
- Useful suggestions are provided on how to integrate program with the regular curriculum.
- If the program is open-ended, subject-specific suggestions are included.
- Clear explanations of the differences between the various difficulty levels are provided.
- Prerequisite skills are clearly stated.
- Accurate and clear description of instructional activities are provided.
- Accurate and clear descriptions of content topics are provided.
- Where appropriate, a description of how material correlates to standard textbook series is provided.
- Necessary information can be found quickly and easily (e.g., contains index, table of contents).
- Quick reference card for program use is included, where appropriate.
- Printed text is clear and readable.
- Printed graphics are clear and readable.
- Printed text is free of errors in spelling, grammar, punctuation, and usage.

Technical Quality

General

- Audio can be adjusted (i.e., turned down or off).
- Audio is clear and used effectively.
- Character sets used in text display are clear, appropriate, and visually interesting.
- Graphics are acceptable on a monochrome monitor.
- Graphics are clear and can be easily interpreted.
- Program is "crash-proof."
- Program runs consistently under all normal conditions and is "bug-free."
- Program runs without undue delays (e.g., graphics fill in a timely manner, does not excessively access disc drive).
- The transitions between screen display are effective (e.g., text changes).
- Program guards against multiple key presses advancing the student past the next screen (e. g., leaning on return key and thereby missing several screens as they flash by).
- Program avoids unnecessary or inappropriate moving back and forth between screens (e.g., from page to feedback or data pages).
- Special features (e.g., flash, inverse, scrolling, split screen) are used appropriately and effectively.
- Program requires a minimal amount of typing (except typing programs).

- Random generation or selection is used when appropriate (e.g., to allow repeated use by varying the problems or data presented).
- Program judges responses accurately and accounts for minor variations in the format of the input (e.g., accepts either the correct word or letter choice in a multiple choice item).
- Program allows user to correct answer before being accepted by the program.
- Program accepts partial answers as correct whenever appropriate.
- Where students must input responses, inappropriate keys are disabled.
- Control keys are used consistently.
- Students require a minimum amount of teacher supervision while using the program, when appropriate.
- Computer (and peripherals) operation does not interfere with concentration on activity.
- Program makes effective use of peripheral devices (e.g., joysticks) for alternate input modes while still allowing keyboard input.
- Program considers a previously unexplored potential of the computer or greatly expands an existing capability (e.g., new animation techniques, digitized speech).
- Program uses other technologies (e.g., audio cassette, videodisc, videotape) to enhance learning, when appropriate.
- Printing is easy and simple to accomplish with a variety of popular printers.

Clarity

- Procedural and instructional statements are clear.
- On-screen prompts clearly indicate where user should focus attention.
- Frame formatting is clear, uncluttered, and consistent from screen to screen (e. g., screen input is restricted to a consistent location),
- Presentation of each discrete content topic is logical.
- Sequence of content topics and instruction is logical and in appropriate steps.
- Sequence of menu items is logical.
- Prompts and cues are clear and consistently and logically applied.
- Hints are clear and not misleading (e.g., length of spaces in fill-in blanks matches number of letters needed).
- Demonstrations and examples are clear and available when appropriate.
- Interface is simple enough to be used with little or no reading of the documentation.
- Program makes clear where the user is in the program (e.g., question number, page headings).
- User-computer communication is consistent and logical.
- Prompts to save work are given when appropriate.

Start-up and Implementation

Teacher:

- Software code modifications or unusual manipulations of discs are not required to use program effectively.
- Start-up time for teacher implementation is not excessive.
- Teacher needs a minimum of computer competencies to operate program (e. g., does not require installing add-on boards).

Student:

- Start-up time for student implementation is brief enough to permit completion of a lesson.
- Students need a minimum of computer competencies to operate program (e.g., does not require use of control-key combinations).

Graphics and Audio

- Graphics and audio are used to motivate.
- Graphics and audio are appropriate for the intended student population.
- Graphics, audio, and color enhance the instructional process.
- Graphics help focus attention to appropriate content and are not distracting.

Probeware and Peripherals Included in the Software Package

- Probes or peripherals are durable.
- Probes or peripherals are sensitive.
- Audio and/or graphic quality are effective.
- Probes or peripherals are easy to install.
- Calibration is accurate and easy.
- Data displays are flexible (e.g., can be scaled, redrawn).
- Data analysis is useful.

Hardware and Marketing Issues

- Potential usefulness of the program justifies its price in comparison to other similar products.
- Peripherals (not included in the package) that are difficult to acquire or inappropriately expensive are not required.
- Producer field test data are available.

- Field test data indicate that students learned more or better, or had a better attitude toward the subject matter, as *a* result of using the program.
- Preview copies are available.
- Back-up copies are provided.
- Adequate warranty is provided.
- Telephone support is available.
- If allowable, multiple loading is possible.
- Site license is available.
- Network versions are available.
- Multiple copies discount available.

U.S. Department of Education Principal Programs Providing Funds for Technology in Education

Funding for educational technology is available through various programs administered by the U.S. Department of Education. In a few cases, funds are appropriated specifically for educational technology. Other funds are obligated for technology projects through existing program areas. And some funds are used for technology activities by recipients of grants and awards that are not designated specifically for educational technology (e.g., grants to States, districts, educational research laboratories and centers). Federal block grants and other grants to States and school districts, such as those for compensatory education for the disadvantaged, mathematics and science education, bilingual education, special education, vocational and adult education, and teacher training, support use of technology at the discretion of States and school districts. Under some programs, grants are awarded and budget decisions are made based on priorities of the Secretary of Education and department administrators.

The following table provides an estimate of levels of funding and support for educational technology within programs administered by the Department of Education.[1] Because funding for educational technology is not closely monitored and data on local use of Federal grants is limited, most figures are estimated. Where Federal grants to States, districts, schools, or individuals are sources of funding for technology and may be used for technology at local discretion, total appropriations are given (e.g., Chapter 2 block grants, magnet schools assistance), A question mark (?) indicates that OTA was not able to estimate the amount of funding for technology.

Since outlays for technology are often not known until several years after the original appropriation, most figures are *estimates* of obligations or expenditures for educational technology for the designated fiscal year. The figures for fiscal year 1989 are department appropriation requests or program estimates based on pending legislation and awards.

	1987 Appropriation[2] (in millions)	Technology Estimate	1988 Appropriation (in millions)	Technology Estimate	1989 Request (in millions)	Technology Estimate
Education Consolidation and Improvement Act:						
Chapter 1 Block Grants	3,453.50	?	$3,829.60	?	$4,060.20	?
Chapter 2 Block Grants	500.00	$150.00[3]	478.70	$143.60[3]	540.50	$162.20[3]
Secretary's Discretionary Fund:						
National Diffusion Network	10.70	0.31	10.20	0.15[4]	10.20	?
Other discretionary programs[5]	1.50	?	4.70	?	9.50	?
Elementary and Secondary Education Act of 1965:						
Title VII—Bilingual Education Act:						
State and Local Grants	99.20	?[6]	101.20	?	13.10	?

(continued on next page)

Abbreviations: OB = Obligation; EO = Estimated Obligation

[1]This table is based on review of budget documents, lists of grants and awards, published research and documents, conversations with program staff at the U.S. Department of Education, and estimates provided by various programs in the Department of Education.

[2]Figures are appropriations or budget requests as indicated unless otherwise noted.

[3]OTA estimates based on a study finding 30 percent of all local Chapter 2 expenditures in the 1984-85 school year were used for technology-related activities. SRI international and Policy Studies Associates, "The Educational Block Grant at the Local Level: The Implementation of Chapter 2 of the Education Consolidation and Improvement Act in Districts and Schools," prepared for the U.S. Department of Education, January 1986, p. 45.

[4]Seven projects were funded in 1987 and several are in their final year. OTA estimates that awards for technology-related projects will decrease in 1989.

[5]Educational technology could be a priority area but currently is not. Priorities for 1989 include teacher certification and recruitment and early childhood education,

[6]Of the 628 grants awarded to districts in 1987, 228 (or 36 percent) included a technology component.

	1987 Appropriation (in millions)	Technology Estimate	1988 Appropriation (in millions)	Technology Estimate	1989 Request (in millions)	Technology Estimate
Education for Economic Security Act:						
Title 117–Mathematics and						
Science Programs						
State Grants	72.80	?	108.90	?	108.90	?
Secretary's Discretionary Fund:						
Technology Competition	0	0	1.00	1.00 (EO)	?	?
Mathematics, Science and						
Critical Foreign Language						
Competitions [8]	3.70	0.53 (OB)	6.60	0.97 (EO)	?	?
Educational TV	3.25	3.25 (OB)	2.25	2.25[9] (EO)	?	?
Title VII–Magnet Schools Assistance . . .	75.00	?	71.80	?	115.00	?
Continuing Resolution–1987						
Star Schools	0	o	19.10	19.10	0	0
Small Business Innovation						
Research [11]	1.70	1.70 (OB)	1.70	1.70 (EO)	1.70	1.70 (EO)
Higher Education Act:						
Title V-C–Leadership in						
Educational Administration	7.20	?	8.20	?	4.40	?
Title V-D–Christa McAuliffe						
Fellowships for Outstanding						
Teachers	2.00	?	1.90	?	1,90	?
Fund for the Improvement of						
Post-Secondary Education	12.20	?[12]	11.60	?	13.60	?
Education for the Handicapped Act:						
State Grants.	1,568.00	?	1,699.80	?	1747.70	?
Special Purpose Programs:						
Technology for Special						
Education	4.67	4.67	4.79	4.79	4.79	4.79
Early Childhood Education	24.50	0	23.40	0	23.40	0.30 (EO)
Media and Captioning						
Services	13.80	13.80	13.20	13.20	13.20	13.20
Personnel Development	67.70	2.29 (OB)	66.40	1.81 (EO)	66.40	1.2? (EO)
Vocational Education Act (Perkins Act):						
Title II–State Grants	802.90	?	791.80	o	835.20	?
Vocational Education Research						
Center	6.00	0.19 (EO)	6.00	?	6.00	?
High Technology						
Demonstrations	0	0	9.60	9.60 (EO)	9.60	9.60 (EO)
Job Skills Education Program	0	0	0.13	0.13 (EO)		?

[7]The Elementary and Secondary School Improvement Amendments of 1988 (Public Law 100-297) revises Title II, authorizes a new program for foreign language education, and eliminates the restriction on the use of Title 11 funds for computer education only after mathematics and science needs have been met. Now, in addition to using Title II funds for preservice training, inservice training, teacher retraining, and minority recruitment, Local Education Agencies (LEAs) may use Title 11 funds for teacher training in technology as *part of* a mathematics and science program. LEAs may also use Tide 11 funds to purchase computers and other telecommunications equipment and to provide grants to individual teachers for Innovative projects in mathematics and science. In addition, States may use their share of Title II funds for demonstrations and exemplary programs for instructional materials and equipment in mathematics and science, as well as to provide technical assistance.

Grants for programs of national significance in mathematics, science, computer education, and critical foreign languages are also appropriated under Title IL The new law gives the Secretary of Education discretion to award grants to support foreign language education separately and focuses the programs of national significance on mathematics and science. Budget figures reflect Title 11 as originally enacted.

[8]The Department of Education estimates that 18 to 20 percent of funds for field-initiated competition and 10 percent of funds for critical foreign language are used for applications of technology.

[9]Includes $1 million for ***Square One TV,*** currently under review.

[10]No data on the percent of magnet school funds used for technology is available, although a recent OTA estimate suggests that **25 percent** is used for mathematics and science magnet schools. Technology could be a component in these and other magnet school programs. See U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School,* OTA-SET-377 (Washington, DC: U.S. Government Printing Office, June 1988).

[11]Funding is based on a percentage of the U.S. Department of Education's external research **budget.**

[12]Some awards support curriculum development and teacher training activities that could be applied to elementary and secondary education. While educational technology was one of the Fund for the Improvement of Post-Secondary Education's (FIPSE) priorities from 1981 to 1985, it is no longer a priority area. Of 176 new and continuing projects funded by FIPSE in 1987, 41 (23 percent) revolved technology.

	1987 Appropriation	Technology Estimate	1988 Appropriation	Technology Estimate	1989 Request	Technology Estimate
	(in millions)		(in millions)		(in millions)	
Adult Education Act:						
Grants to States	106.00	?	115.40	?	148.20	?
State Grants to Local Education Agencies[13]		2.86		3.11		3.99
State Discretionary Grants[13]		1.51		1.65		2.11
Field Initiated Research	0	0	1.90	0.90-1.25 (EO)	2.00	.90-1 .25 (EO)
Office of Educational Research and Improvement:						
Field Initiated Research	0.60	0.06 (OB)	0.50	?	1.00 (EO)	
National Research and Development Centers[14]	17.50		17.50		17.50[16]	
All Centers excluding Educational Technology Center[15]		1.00 (EO)		1.00 (EO)		1.00
Educational Technology Center		2.00		0.90 (EO)		.00 (EO)
Regional Educational Laboratories .	17.00	1.8 (EO)	17.00	1,23 (EO)	17.00	.15 (EO)
Technology Conference and "What Works" . .	0	0	0	o	0.10	0.10
Educational Resources Information Network (ERIC)[17]	5.70	0.29 (OB)	5.70	0.30	5.70	
Center for Statistics	9.10	?	13.40	?	20.00	?

[13] A minimum of 10 percent of the grants awarded to States must be set aside for training, research, demonstration, and evaluation. The remaining State grant goes to LEAs, post-secondary institutions, and community organizations.

[14] The award for the Educational Technology Center is included in the total center appropriation of $17.5 million.

[15] Estimates were provided by the research centers and the U.S. Department of Education. Amounts do not reflect other research in learning that may relate to the use of technology in the future.

[16] Two new centers are proposed in the Secretary's 1989 budget. One center will study the needs of at-risk students. A second smaller center will study a range of educational issues including the teaching and learning of civics and citizenship, examination and assessment of education reform initiatives, research into student motivation, and studies of costs and productivity in education.

[17] One of the 16 ERIC clearinghouses focuses on educational technology. It is based at Syracuse University and its budget is reflected in the technology estimate column.

Appendix D

List of Acronyms

ACOT —Apple Classroom of Tomorrow
AI —artificial intelligence
ASCII –American Standard Code for Information Interchange
ASSET –Arizona School Services Through Educational Technology Project
AT&T –American Telephone and Telegraph
CAD —computer-aided design
CAI —computer-assisted instruction
C-AIM —computer-assisted instructional management
CAM —computer-aided manufacture
CCC –Computer Curriculum Corp.
CCSSO –Council of Chief State School Officers
CD-I —compact disc interactive
CD-ROM–compact disc-read only memory
CD-V —compact disc video
CDC –Computer Data Corp.
CMI —computer-managed instruction
CTBS –Canadian Test of Basic Skills
DISE —Development in Science Education
DVI —digital video interactive
ECIA —Education Consolidation and Improvement Act
EESA –Education for Economic Security Act
EPIE –Educational Products Information Exchange
ERIC –Educational Resources Information Center
ESAA –Emergency School Aid Act
ESC –Education Service Center
ESC –Education Systems Corp.
ESOL –English for Speakers of Other Languages
fax —facsimile transmission
HOTS —Higher Order Thinking Skills Program
ICAI —intelligent computer-assisted instruction
ILS —integrated learning system
IMPAC –Instructional Microcomputer Project for Arkansas Classrooms
ISDN –Integrated Services Digital Network
ITV —instructional television
JTPA –Job Training Partnership Act
K –kilobyte
LAN –local area network
LD –learning disabled
LRDC –Learning Research and Development Center
MBLs —microcomputer-based laboratories
MECC –Minnesota Educational Computing Corp.
METN –Maryland Education Technology Network
NCTI –National Computer Training Institute
NIE —National Institute of Education
OCA —Office of Computing Activities
OECC –Oregon Educational Computer Consortium
OERI –Office of Educational Research and Improvement
OSR –Operation School Renewal
PHEAA –Pennsylvania Higher Education Assistance Agency
PROM —programmable read only memory
PTA —Parent-Teacher Association
PTO —Parent-Teacher Organization
R&D —research and development
RAM —random access memory
RCRC —Regional Computer Resource Centers
RISE –Research in Science Education
ROM —read only memory
SAGE –Semi-Automatic Ground Environment for Air Defense System
SBIR –Small Business Innovation Research
SDE –State Department of Education
SEE –Science and Engineering Education
SEED —Software Evaluation Exchange Dissemination Project
SES —socioeconomic status
TEC —Technology Education Center
TEC —Teacher Education and Computer Center
TERC. –Technical Education Research Centers
TIC —Technology in the Curriculum Projects
VCR —videocassette recorder
WAN —wide area network

Appendix E

Contractor Reports

Copies of contractor reports done for this project are available through the U.S. Department of Commerce, National Technical Information Service (NTIS), Springfield, VA 22161, (703) 487-4650.

1. "An Analysis of the Scope and Quality of the Current Supply of Educational Software, and of the Available Sources of Information on Educational Software," Ellen R. Bialo and Jay P. Sivin, Interactive Educational Systems Design, Inc. (NTIS order number PB 88-194 667/AS)
2. "Support for Educational Technology R&D: The Federal Role," Charles Blaschke, Beverly Hunter, and Andrew Zucker, Educational Turnkey Systems, Inc. (NTIS order number PB 88-194 626/AS)
3. "Influences on Development and Innovation in Educational Technology, " Dean Brown, Ted M. Kahn, and Marvin M. Zauderer, Picodyne Corp. (NTIS order number PB 88-194 642/AS)
4. "Computers and Learning: Do They Work? A Review of Research, " Joanne Capper, Center for Research Into Practice (NTIS order number PB 88-194 683/AS)
5. "Computer Networks in Elementary and Secondary Education," Earl Dowdy, University of Illinois, Urbana (NTIS order number PB 88-194 675/AS)
6. "A Review of the Status of Technology Training for Teachers," Allen D. Glenn and Carol A. Carrier (NTIS order number PB 88-194 766)
7. "Mechanisms for Facilitating a Vital and Dynamic Education System: Fundamental Roles for Education Science and Technology," Roy D. Pea and Elliot Soloway, Cognitive Systems, Inc. (NTIS order number PB 88-194 634/AS)
8. "Educational Technology: Information Networks, Markets and Innovation," W. Curtiss Priest, Center for Information Technology and Society (NTIS order number PB 88-292 836/AS)
9. "Assessing Cost-Effectiveness of Computer-Based Technology in Public Elementary and Secondary Schools," David Stern and Guy Cox, University of California, Berkeley (NTIS order number PB 88-194 659/AS)
10. "Alternative Approaches to Developing a Cadre of "Teacher Technologists," J.H. Strange, S.A. Tucker, G.E. Uhlig, and P. Feldman, Acadia Educational Enterprises, Inc. (NTIS order number PB 88-194 774/AS)
11. "How Technology Affects Teaching," Martha Stone Wiske and Philip Zodhiates, Harvard University, Educational Technology Center (NTIS order number PB 88-202 622/AS)

Appendix F

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