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.

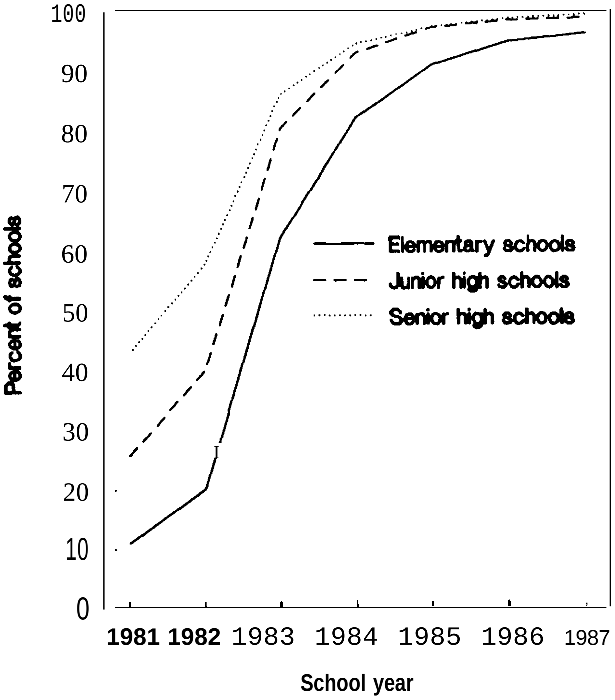
THE SPREAD OF TECHNOLOGY IN SCHOOLS

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

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.

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.

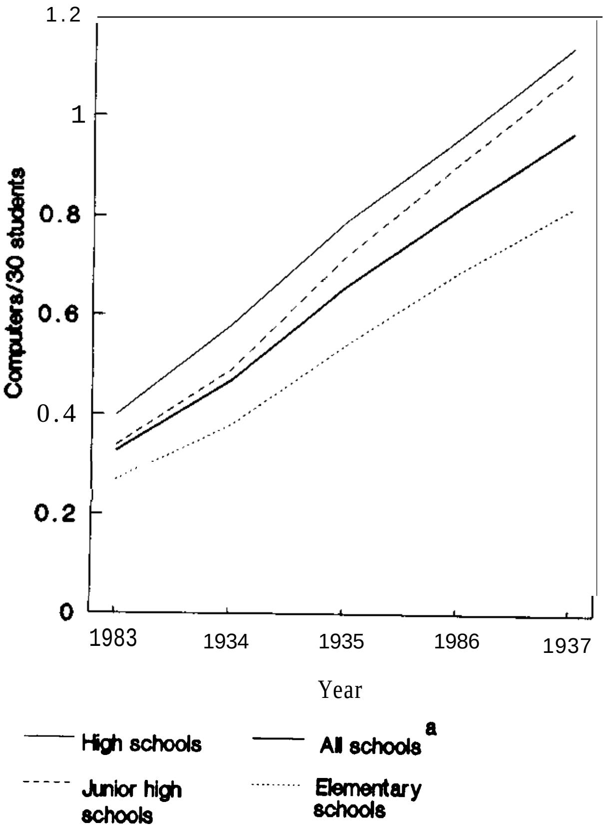
Furthermore, in analyzing these and other current data available on computer use by different demographic characteristics, OTA found that students in relatively poor elementary or middle schools have significantly less potential access to computers than do their peers in relatively rich schools. Black

[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



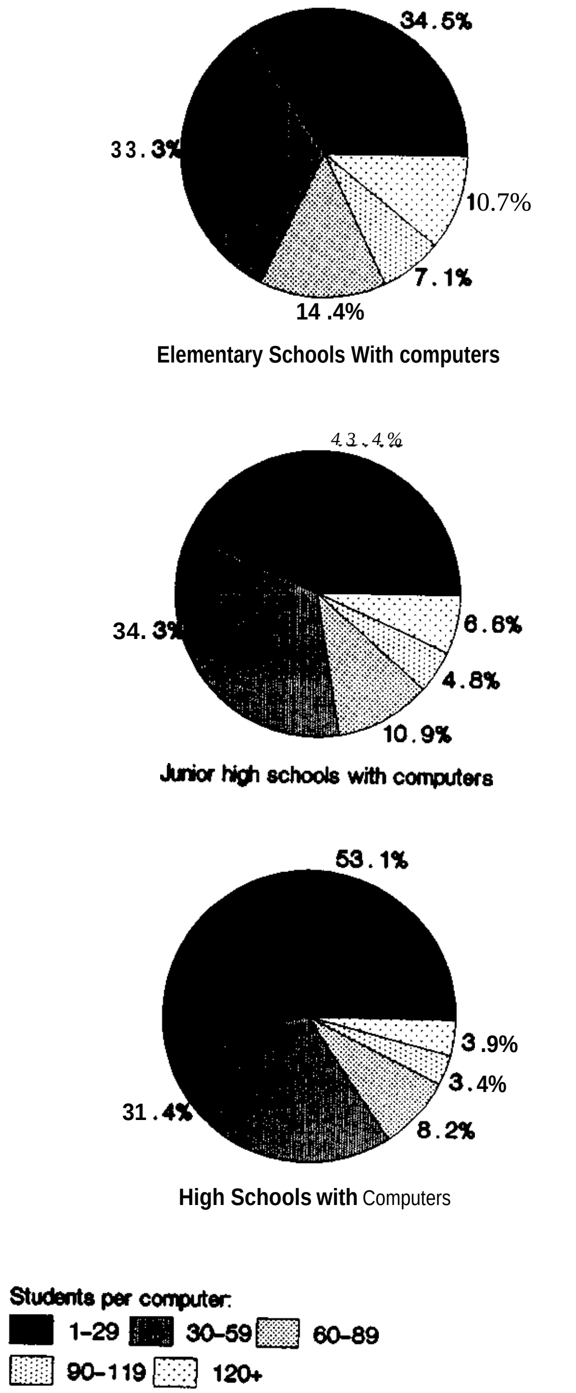
aIncludes K-12 combined schools.

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

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-

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,

[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

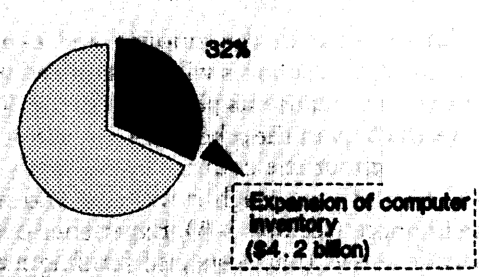
	Cost (in millions)	Annual cost (in millions)
Capital costs for hardware[a]		
12 million computers @ $1,000 each	$12,000	
5 million printers @ $400 each	2,000	
Total	$14,000	
Annualized cost, assuming 6-year equipment life and 10% interest rate		$3,200
Other annual costs		
Software @ $5/student	$200	
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.**

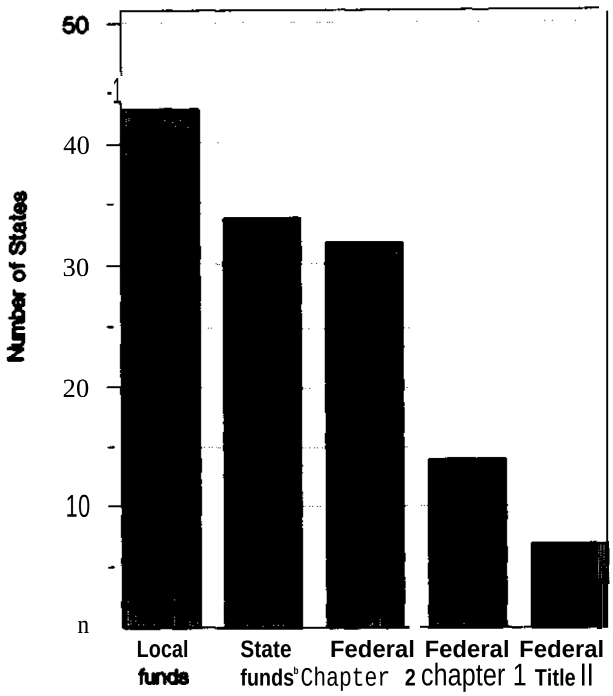
Teacher Association, or business contributions, or a combination of these support technology used by school districts. (See figure 1-4.) Costs include purchases of technology, teacher training, maintenance, continuing upgrades of hardware and software, and supporting personnel.[12] (See table l-l.)

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 H ill-C arrboro 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" (Tide 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 1 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.

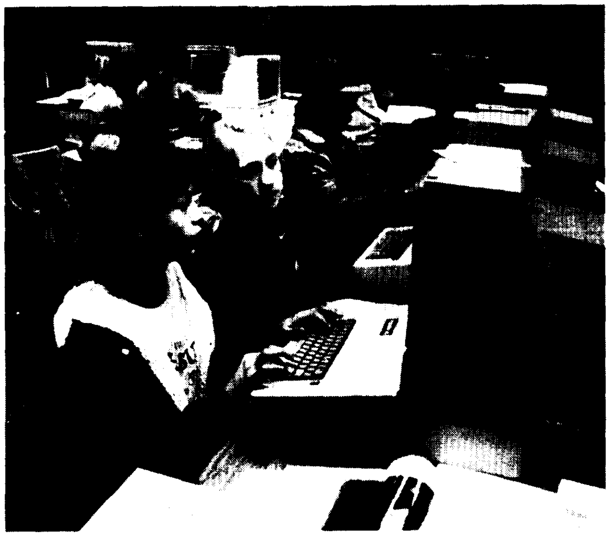


Photo credit: **BreadNet Project**

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.

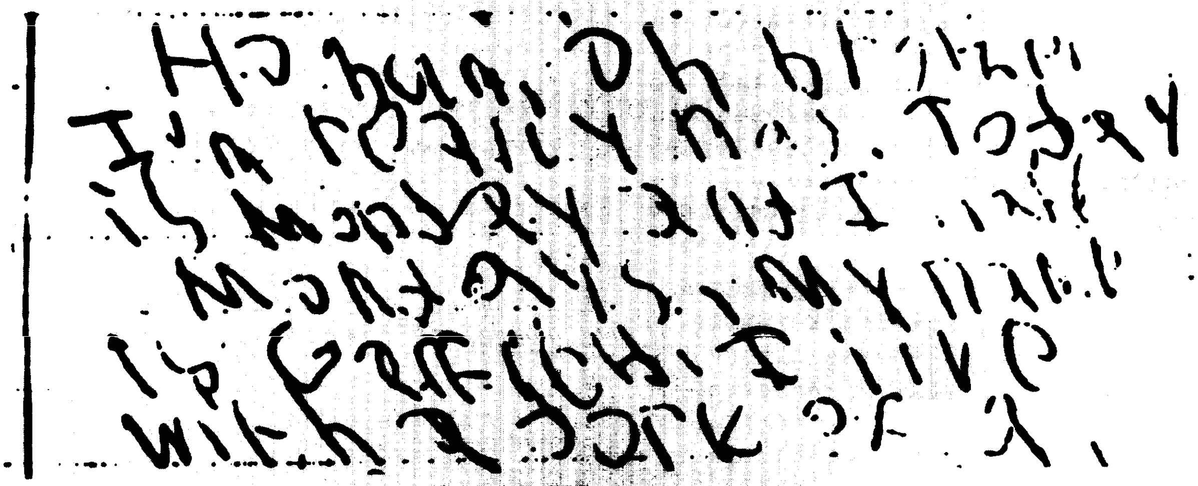
Cooperative learning.–The new technologies can encourage cooperative learning. Telecommunications technology, by definition, makes new forms of communication and cooperation possible. On an electronic network, students from many locations can gather information from many sources. Teachers are especially 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

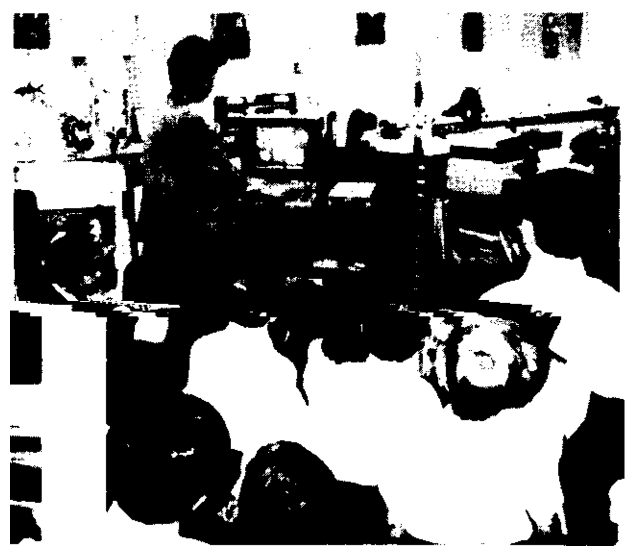


Photo credit: Computer Learning Month

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.

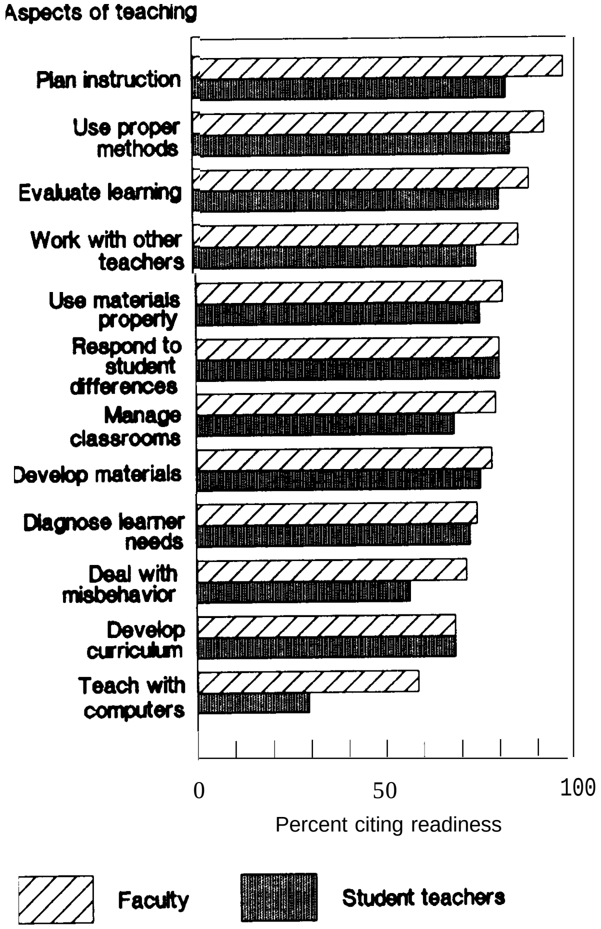
The situation is no more promising for those just entering teaching. A recent national survey of education majors indicated that less than one-third (29 percent) perceived themselves to be prepared to teach with computers.[21] (See figure 1-5.) Although almost all teacher education programs provide some 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



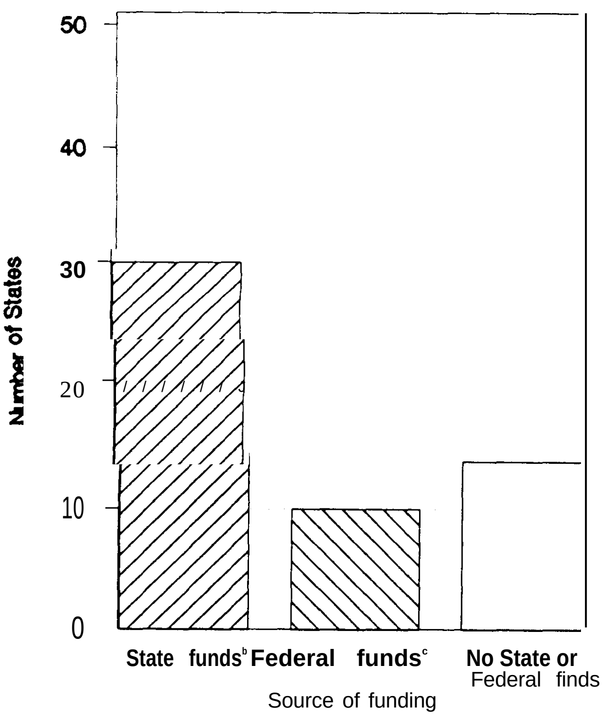
SOURCE: Research About Teacher Education Project, Teaching *Facts and Figures* (Washington, DC: American Association of Colleges for Teacher Education, 1967).

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 1-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 1-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 l-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

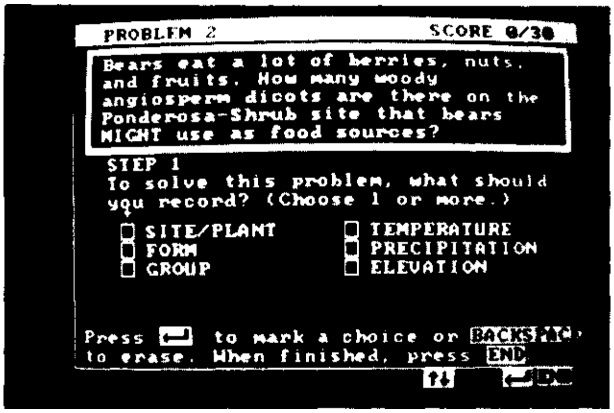
[a]The sum of the programs is greater than N because some programs were assigned to more than one category. Accordingly, the total of the percentages is greater than 100 percent. All percentages were rounded to the nearest unit.

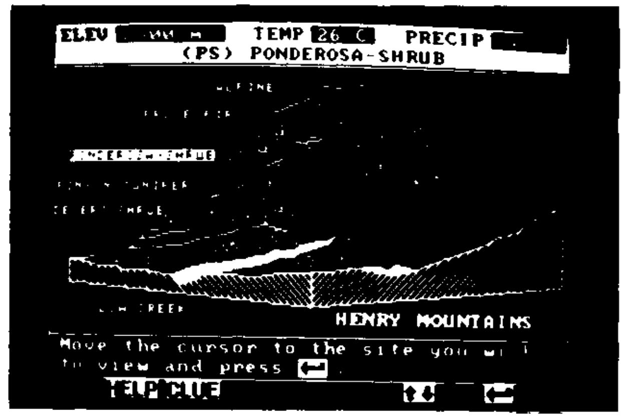
SOURCE: Office of Technology Assessment baaed on analysis of data in the Educational Products Information Exchange, July 1987.

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.

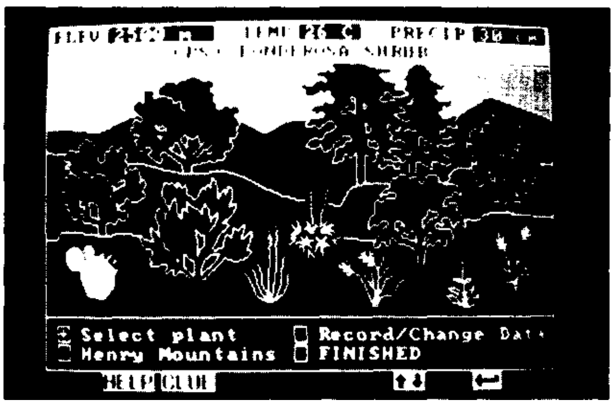
This propensity toward producing familiar instructional materials is not limited to small entrepreneurs. OTA finds that large firms, with greater capital resources, do not necessarily take larger risks; integrated learning systems, for example, have a greater chance of being attractive to school districts 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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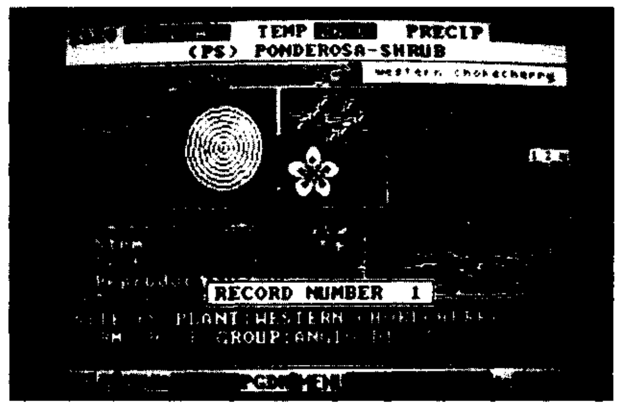

Students use the database to record the data they need to solve each problem. After gathering their data, they summarize their answers and receive a printout of the problem, data, and answers.

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.

[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]

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.

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]

[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, 1985, 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 percent, 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 demonstration; 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.