Chapter 7

Research and Development: Past Support, Promising Directions

Photo credit: Charles Babbage Institute, University of Minnesota

The ENIAC (Electronic Numerical Integrator and Automatic Computer), circa 1946.

[Page Omitted]

This page was originally printed on a gray background.
The scanned version of the page is almost entirely black and is unusable.
It has been intentionally omitted.
If a replacement page image of higher quality
becomes available, it will be posted
within the copy of this report
found on one of the OTA websites.

Chapter 7

Research and Development: Past Support, Promising Directions

INTRODUCTION

American education is at a crucial juncture. The demands on schooling in our pluralistic society are greater than they have ever been. An increasing percentage of students are educationally at risk, and demographic projections make clear that this problem will continue to grow. In addition, schools must prepare all young people with a new set of skills and understandings to assure the Nation's economic competitiveness. At the same time, technology makes it possible to consider real improvements in the productivity of both teaching and learning. Taken together, these forces could change what is taught, when it is taught, how it is taught, and the nature of teaching as a profession.[1] **Because of the great promise offered by interactive technologies for learning, Congress needs to consider a substantial Federal investment in research and development (R&D) to exploit more fully the power and potential of technology for education.**

In the past, education has been at the far end of the information technology R&D pipeline. Ideas have taken up to 20 years to move from basic research to school application. Although the technology is changing rapidly, current policies inhibit the flow of ideas along the continuum from research to development, evaluation, and dissemination. Many barriers block this flow. They include the absence of a coordinated Federal policy, limited and short-term funding, erratic political support, and disorganized R&D efforts across agencies. As a result, many opportunities have been delayed; others may have been lost altogether.

[1]See U.S. Congress, Office of Technology Assessment, *Technology and the American Economic Transition: Choices for the Future,* OTA-TET-283 (Washington, DC: U.S. Government Printing Office, May 1988), pp. 47-49.

FINDINGS

- Public education K-12 is a $150 billion a year business. The Federal Government spends not even 0.1 percent of that amount on research to improve it.
- The Department of Education's $128 million share of the $63 billion fiscal year 1988 Federal R&D budget amounts to 0.2 percent of all Federal R&D. And the Department of Education's own budget devotes less than 0.5 percent to research.
- Funding for educational technology R&D has been inconsistent over the last 30 years. Educational priorities have been buffeted by the winds of political change, making long-term commitments rare.
- With no lead agency for educational technology R&D and no structure for coordinating activities across agencies, there has been no strategic planning, little long-term evaluation, and missed opportunity for transferring findings across agencies with similar research interests. Despite these difficulties, some of the best educational technology products in use in schools today are the outcomes of Federal investments in R&D since the 1960s.
- Military agencies provided approximately three-quarters of all funding for educational technology research over the last three decades, supporting much of the early work on computer-assisted instruction (CAI), cognition, and simulation for

skills training. Research in artificial intelligence and advanced computing applications continues to be important for education, but military research may no longer be the patron of such work.

- Where civilian R&D finding for educational technology has been focused and consistent, the investment has produced important results. Examples include technology to improve educational opportunities for the handicapped and learning disabled; development of public broadcasting facilities and innovative children's programming, from *Sesame Street* to *Square One TV;* and the development of LOGO, a computer programming language for children.

Research in cognitive science, allied with developments in computer-based technology, the installed base of technology in the schools, and teachers willing to experiment create today's "window of opportunity" for improving education. R&D seeding could bear fruit. Among the most promising new research developments are:

- Intelligent tutoring systems that can make the services of an expert and responsive tutor regularly available to the learner.
- Applications that exploit the computer as a flexible multimedia controller, enhancing curriculum with the richness of video, graphic, and audio representations of information.
- Simulations, microworlds, and exploratory laboratory experiences in all disciplines that enable students to gain understanding through exploration, manipulation, and guided discovery.
- Integrated tools and "intelligence extenders" that help students to move beyond low-level tasks and concentrate instead on more cognitively demanding learning and problem solving.
- New assessment measures that track learning, diagnose students' conceptual understandings, and evaluate the attainment of nontrivial skills.
- Design tools, authoring systems, and knowledge kits that enable teachers to create and shape their own teaching materials, to modify curriculum, or develop individualized lessons for their students.
- New curriculum based on a changing vision of the skills students need in the information age, shifting much of the emphasis from what *to learn* to *how to learn.*

Promising developments require closer ties between the research community and the classroom and contributions from many fields.

- A new dialog must be established among teachers, researchers, and school administrators to tie classroom needs and realities to promising research findings and technology applications. Without close ties between the laboratory, the design facility, and the classroom, technology that is needed may not be developed; that which is developed may not be adopted or successfully used by teachers.
- Educational technology R&D requires interdisciplinary research, pulling together expertise in cognitive science, artificial intelligence, computer science, anthropology and sociology, psychology, instructional design, and education. Interdisciplinary researchers are in short supply, and their research requires stable, long-term investments, to support advanced hardware and software and to sustain projects from prototype development to evaluation in real school settings.

OTA concludes that the Federal Government must play a much greater role in supporting and coordinating research, development, and demonstration in educational technology. While the States and local districts can and will support some aspects of technology implementation, and private industry should continue to play a role, neither the States, the districts, nor the private sector has the capacity or incentive to conduct long-term research, promote comprehensive development, or disseminate promising results.

EDUCATION AND R&D: A NATIONAL PERSPECTIVE

The national investment in education and training is huge. As a nation we spend somewhere in the range of $300 to $500 billion a year on all types of education and training, in schools and in industry.[2] About $150 billion of that is spent by States, localities, and the Federal Government on public education. The Department of Education's budget request for fiscal year 1989 is $21.2 billion.

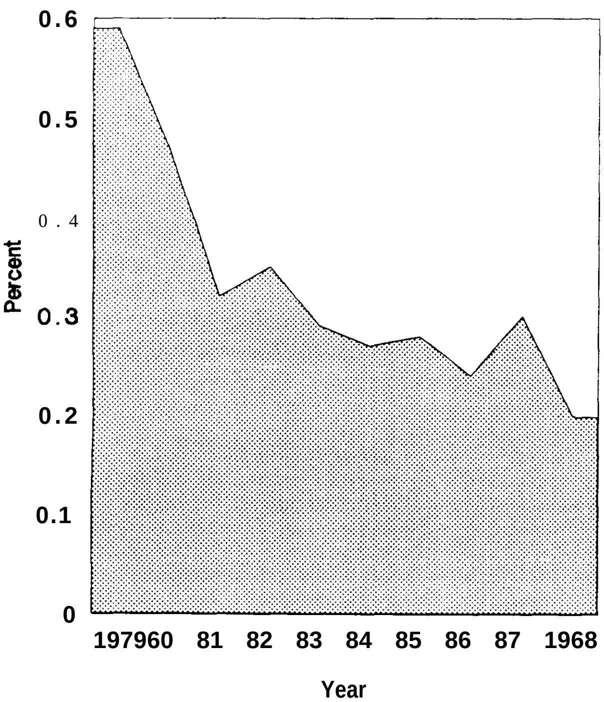
R&D is also a major investment. The United States currently invests over $120 billion per year, just under 3 percent of the gross national product, in public and private R&D. The Federal Government share of R&D is $63 billion, 62 percent of which is military R&D. Education R&D commands less than 0.1 percent of the Federal R&D budget (see figure 7-1). Since 1980, funding for education R&D has decreased dramatically, while both Federal and overall spending for education increased.[3] Moreover the National Institute of Education's expenditures for research have decreased since the early 1970s by more than 70 percent in constant dollars at the same time that the overall Federal investment in education increased by 38 percent[4] (see figure 7-2a and b).

[2]Ibid., p. 47.

[3]See U.S. Congress, Congressional Research Service, U.S. *Department of Education: Major Program Trends, Fiscal Years 1980-89*, Report 88-330 EPW (Washington, DC: April 1988), pp. 97-100; and U.S. Congress, General Accounting Office, *R&D Funding: The Department of Education in Perspective*, Report PEMD-88-18FS (Washington, DC: May 1988).

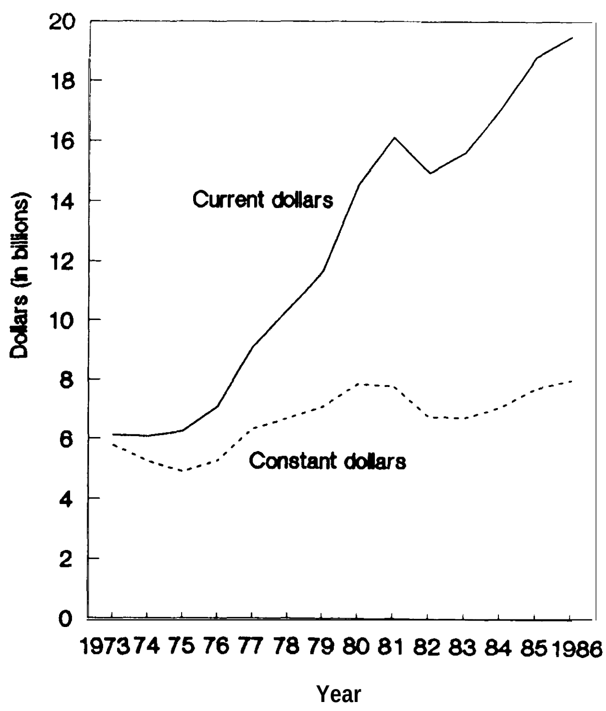
[4]For a fuller analysis, see U.S. Congress, General Accounting Office, *Education Information: Changes in Funds and Priorities Have Affected Production and Quality*, Report PEMD 88-4 (Washington, DC: November 1987).

Figure 7-1.—Obligations for R&D in the U.S. Department of Education as a Percent of All Federal R&D Obligations, 1979-88



SOURCE Office of Technology Assessment, based on National Science Foundation, "Federal Funds for Research and Development," detailed statistical tables, 1987.

Figure 7-2a.—U.S. Department of Education Obligations in Current and Constant 1972 Dollars for Fiscal Years 1973-86[a]



[a]Includes the Office of Planning, Budget, and Evaluation, the National Center for Educational Statistics, and the National Institute of Education. Constant 1972 dollars are computed by using the implicit price deflator for federal Government purchases of goods and services as reported in Survey of Current Business.

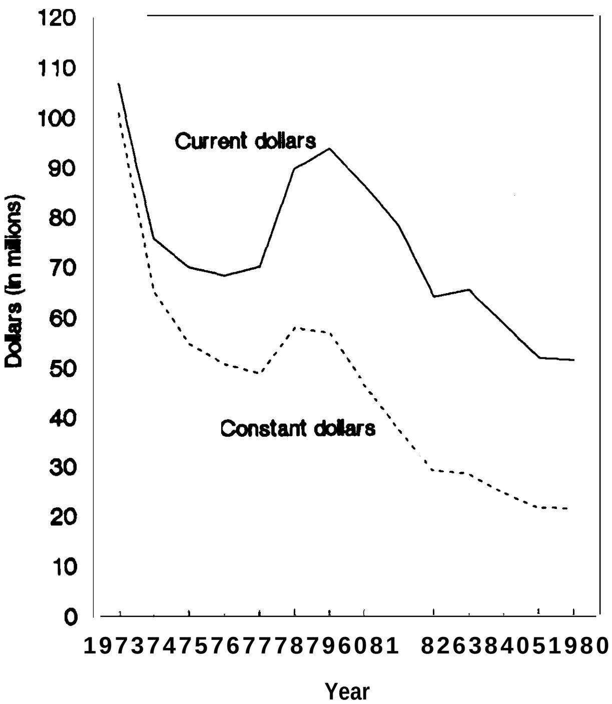
SOURCE: US. Congress, General Accounting Office, "Education Information, Changes in Funds and Priorities Have Affected Production and Quality," Report to the Chairman, Subcommittee on Select Education, House Committee on Education and Labor, November 1987,

FEDERAL SUPPORT FOR EDUCATIONAL TECHNOLOGY R&D'

It is exceedingly difficult to isolate and quantify the exact amount the Federal Government invests in R&D for educational technology. Expenditures are fragmented among and across departments, agencies, bureaus, offices, and programs. It is even harder to trace these funds over the years, because of reorganizations and shifts at all levels of government. OTA's estimate of Federal support for educational technology R&D is based on an analysis of the three agencies that have been the major funders in this area: the Department of Defense (DoD), the National Science Foundation (NSF), and the Office of Education/Department of Education. **Direct Federal funding for R&D which impacts educational technology accounts for total spending of approximately $240 million per year,[6] never approaching the billions committed to other major categories of technology-related R&D, such as energy, agriculture or transportation.**

[5]This section draws heavily on Charles Blaschke et al., Education Turnkey Systems, "Support for Educational Technology R&D: The Federal Role," OTA contractor report, Sept. 30, 1987.

Figure 7-2b.—National Institute of Education Obligations in Current and Constant 1972 Dollars for Fiscal Years 1973-86°



aConstant 1972 dollars are computed by using the implicit price deflator for Federal Government purchases of goods and services as reported in Survey of Current Business.

SOURCE: U.S. Congress, General Accounting Office, "Education Information, Changes in Funds and Priorities Have Affected Production and Quality," Report to the Chairman, Subcommittee on Select Education, House Committee on Education and Labor, November 1987.

The Department of Defense

DoD has played a major role in the development of computer technology and its applications to education and training. In fact, one of the earliest technologies, the chalkboard, was created at West Point. An instructor, Frenchman Claude Crozet, found himself in a dilemma. Unable to speak English and with no textbooks to teach his science course, he painted a wall of his classroom black and wrote on it with chalk.[7] The computer itself was developed using defense R&D funds.

With its growing demand for technologically skilled service personnel able to maintain and operate increasingly sophisticated military equipment, DoD training requirements have increased. As noted by two military analysts:[8]

> A current and probably correct assumption behind U.S. defense planning is that in any major confrontation, ranging from deterrence to combat, our adversaries will be able to supply greater numbers of people than we can. We have sought to counter this superiority in manpower quantity with quality, partly in manpower but primarily in advanced materiel . . . faster tanks, more heavily armed aircraft, more sensitive radar and sonar, more accurate fire-control devices, more powerful and more complex computers to aid tactical and strategic decision

[6]This figure is a rough estimate that includes the Department of Defense manpower and personnel education and training research and development in technology ($207.6 million), the National Science Foundation precollege technology activities ($1 1.8 million), and the Department of Education discretionary research and development technology activities ($18. 1 million) (fiscal year 1987 figures).

[7]C. Anderson, *History of Technology 1: Technology in American Education, 1650-1900*, Occasional Paper No. 1 (Washington, DC: National Education Association, Technological Development Project, 1961); also J.R. Ollsen and V.B. Bass, "The Application of Performance Technology in the Military: 1960- 1980," *Performance and Instruction, vol. 21, 1982.*

[8]J. Dexter Fletcher and Marty Rockway, "Computer Based Training in the Military," *Military Contributions to Instructional Technology (New* York, NY: Praeger Publishers, 1986), pp. 172-173.

> making, and so on. However, we must operate, maintain, and deploy this materiel close to the limit of its intended performance. If we do not, the high cost of the materiel will be wasted, and the competitive edge it is intended to buy will be lost . . . no understanding of military systems is complete without consideration of the human performance they require to function as designed. Put another way, human performance is an inseparable, essential component of every military system. Given this perspective on military-system effectiveness, it is not surprising to discover that the military investment in training is immense.

Furthermore, as more recruits enter the Services with low reading, writing, and mathematics skills, the military has had to spend billions educating and retraining the failed products of our educational system.[9] Investments in instructional technology R&D are viewed by the military as a means of making their huge personnel education and training system more efficient,

The level of DoD's investment for education and training has consistently exceeded that of all Federal civilian agencies combined. The military now spends approximately $208 million a year on R&D technologies in education and training, while civilian spending on technology R&D for K-12 education is estimated at $30 million. Put another way, the military spends $7.00 for every dollar spent by the civilian sector on R&D for instructional technology.

DoD R&D in technology ranges from basic cognitive science investigations to applied development of course materials and electronic teaching machines. Figure 7-3 shows a timeline of representative projects supported by the services since the 1950s. Sustained efforts, combined with large levels of support for projects carried across the R&D continuum, resulted in training applications of direct utility to the military agencies. The military also explored high-risk but potentially high-payoff technology developments that reaped benefits for education (see box 7-A).

Two major lines of support can be traced over time. The first line traces research in programmed instruction leading to applications in CAI and computer-based instruction (CBI), and research in computer-managed instruction (CMI) for individualized training systems for military personnel. Examples along this line of development include:

- PLATO, envisioned as a "book with feedback" as early as 1959, and supported by combined DoD resources for numerous iterations of development.[10] An important component was a large-scale longitudinal evaluation. This evaluation and other studies of PLATO provided important lessons for developing CBI with the next generation of computers.
- The Air Force's Semi-Automatic Ground Environment for Air Defense System (SAGE), a prototype and progenitor for a host of military and civilian computer-based information systems. In designing SAGE it was found most efficient to embed training instruction directly in the system. The system taught the operator how to use it. This concept led to further development of projects utilizing computer controlled instruction in educational systems (e.g., AIRDALE, DIOGENES, and the Advanced Instructional System).
- Applications of the IBM System 1500 for CAI training. The Naval Academy used the System 1500 for CAI in physics, chemistry, Russian, and Naval Operations analysis; while the Naval Station in San Diego and the Army Signal School at Fort Monmouth, New Jersey developed CAI in electronics training.
- Research by the Office of Naval Research (ONR) and the naval laboratories on programmed instruction led to the largest CMI effort of its time, the Naval Air Station project in Memphis, serving more than 6,700 students daily.

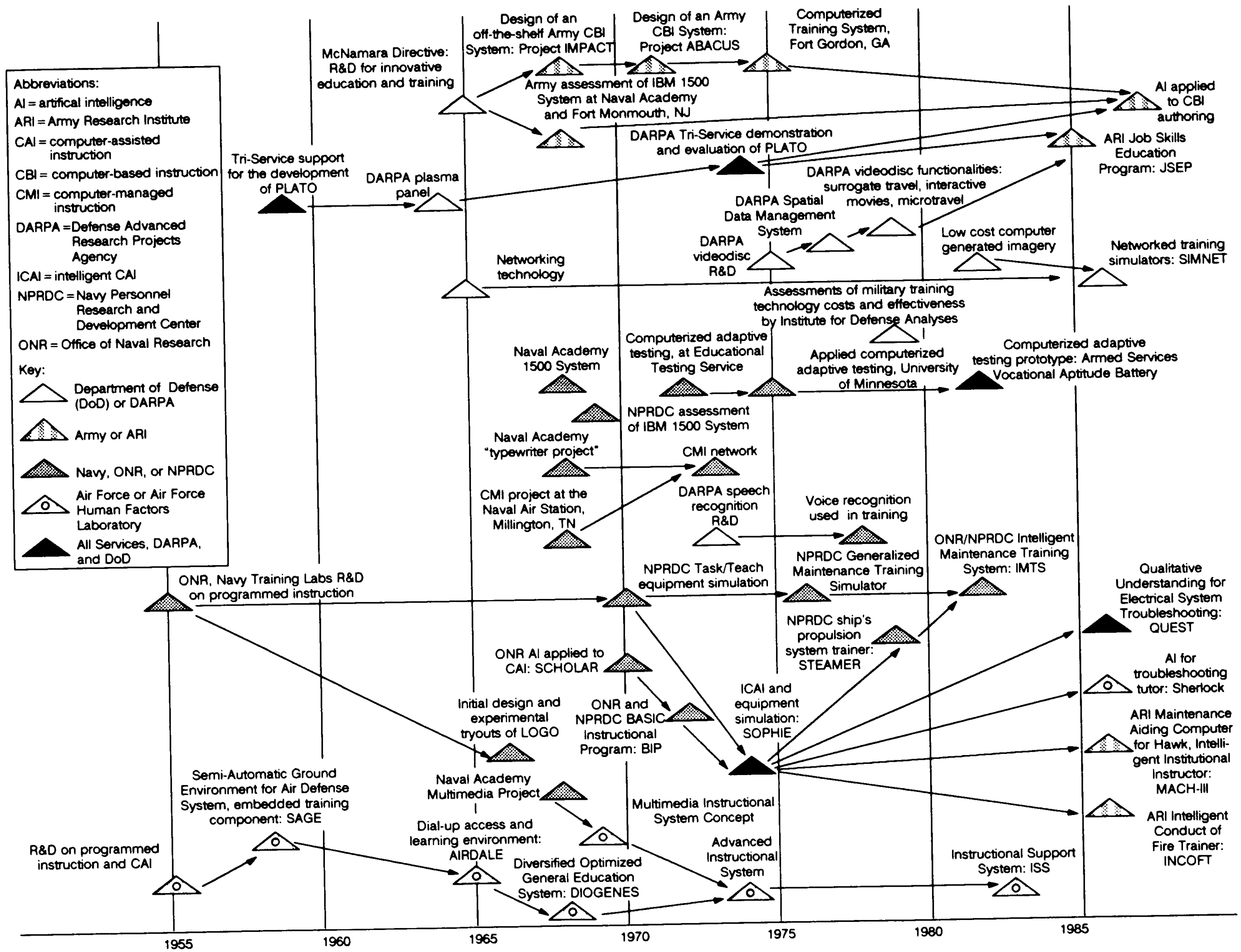
The other major line of research has led to simulations for various training applications, such as:

- Navy's Taskteach Tutorial, which simulated equipment for maintenance training and led to development of a General Maintenance Trainer/Simulator and the Sophisticated Instructional Environment (SOPHIE). SOPHIE received Tri-Service support and is considered the "mother"

[9] It has been estimated that, on an average day in 1984, some 265,000 military and civilian personnel were undergoing some type of formal training, requiring a support staff of another 194,700 personnel, at a cost of $13.3 billion for that year. Ibid., p. 173.

[10] The National Science Foundation also supported development of PLATO in the 1970s. See National Science Foundation section below.

Figure 7-3.—Timeline of Major Instructional Technology Projects in the Defense Agencies, 1955-87[a]



[a]Time-line designation indicates year of project start-up.

SOURCE: Dexter Fletcher, Institute for Defense Analyses, 1988.

Box 7-A.-The Special Characteristics and Contributions of the Defense Advanced Research Projects Agency (DARPA)

DARPA was particularly important for the development of computer technologies, many of which have been applied to education and training applications. The agency was established in 1958 in response to the Sputnik crisis, to explore high-risk but potentially high-payoff technology developments and to protect the United States against technology surprise. While most of DARPA's support focused on air missile and space defense, some observers have called it ". . . the single-most influential government agency for the development of instructionally relevant capabilities such as computer speech interaction and artificial intelligence."[1]

From 1960-75, DARPA funded a number of major projects related to computer-assisted instruction and artificial intelligence. DARPA provided funding arid served as an umbrella for support from each of the services for the PLATO project. During the late 1960s, DARPA also supported path-breaking R&D in artificial intelligence at Stanford and the Massachusetts Institute of Technology. Other developments focused on applications of microprocessor-controlled videodisc technology, such as interactive movies, surrogate travel, and low-cost visual simulators such as the tank gunnery trainer. Other DARPA contributions include developments in computer-based authoring systems, learning strategies, and skills acquisition. Research in the 1980s focused on large-scale networks, computer systems software development tools, tutoring systems, and human factors research in "embedded" training.

In the cognitive science and computer science research community, DARPA was seen as the agency most open to far-reaching ideas. Innovation was encouraged and researchers came to believe that they could walk into DARPA with an interesting idea and walk out the door with a check to try it out. Several characteristics of DARPA in the 1960s and 1970s contributed to this responsiveness:

- Procurement flexibility: Few DARPA contracts followed the traditional competitive bid process, Iargely because it was assumed that some of the expected outcomes could not be adequately prescribed in RFPs.[2]
- Management flexibility: DARPA's staffing philosophy tallowed project officers, themselves highly qualified researchers and scientists, unusual discretion and responsibility but limited their employment to relatively brief periods to minimize empire building and to cross-fertilize the government and outside R&D communities.
- Mission priority and umbrella coverage: The high priority of the DARPA mission was reflected in its position in the Department of Defense hierarchy. Its director reported directly to the Secretary of Defense. DARPA often provided seed or risk money to conceptualize an idea or initiate a small program. As an official noted "The implicit mission of DARPA was to fund important areas of R&D which the services overlooked or refused to support."[3]

Because of its flexible authority and management, DARPA was able to provide continuity, effective communications and continuous support within its R&D community. The initial development and subsequent use of ARPANET, the agency's electronic network, provided unique opportunities for those on the network to exchange information including findings, "bounce ideas off experts," "refine thinking," and test the rigor of research in process.

The long gestation period required for ideas to become useful innovations made DARPA's ongoing support extremely important. However, a recent trend toward more directed and applied R&D projects is now also reflected in DARPA funding priorities. If the research community can no longer look to a DARPA for early and consistent support of innovative concepts, the next decade's innovations may not get any further than the "interesting idea" stage.

---

[1] J. Dexter Fletcher and Marty Rockway, "Computer Based Training in the Military," *Military Contributions to Instructional Technology* (New York, NY: Praeger Publishers, 1986), pp. 206-207.

[2] "Revolutionary not evolutionary is supposed to characterize all DARPA projects. The agency's position is that if a project can be prescribed by a request for proposals, then DARPA should not be doing k." Ibid., p. 206.

[3] Marshall Farr, personal communication, August 1987.

of several other intelligent tutoring systems developed by the services for training personnel in troubleshooting tasks and equipment operation and maintenance.

- Defense Advanced Research Projects Agency (DARPA) research on videodisc technology, which led to interactive movies (allowing the student to control such aspects of viewing as perspective, detail, plot, and simultaneous action), surrogate travel (enabling the learner to "walk" through an area as it is displayed visually and to see what lies ahead or around the corner of each chosen path), microtravel (surrogate travel through places where people cannot go, as through a jeep engine while it is running), spatial data management (allowing users to "fly over" an array of information and select what they want through joystick controls), and low-cost portable simulators such as the tank gunnery trainer.

Early top-level support for R&D in educational technology came from a 1965 memorandum from then Secretary of Defense Robert McNamara to the Secretaries of the Army, Navy, and Air Force. Noting that little was being spent on innovations and new methods and techniques for education and training, the Secretary directed that a line item be placed in the budget for educational R&D ". . . to be used primarily on specific projects directed toward the improvement of existing Defense Department education and training programs."[11] His support was based on evaluations of previous CAI projects showing a 20 percent reduction in training time, the opportunity to individualize instruction, and the ability to control and manage a variety of media projects.

These evaluations of effectiveness have been important for generating ongoing support for projects. Training, in contrast to education, is relatively easy to evaluate, both because of methodology (it provides a tight feedback loop for instruction research and evaluation) and motivation (because training can be linked to specific jobs, cost-effectiveness tradeoffs are more readily and immediately observable than they are in education.)

The military services continue to support important work on basic research on cognition, artificial intelligence, speech recognition, interactive learning systems, and converging technologies. The military has been a major, and occasionally the major, player in advancing the state-of--the-art. Implications for education in the civilian sector are clear. **Computers would probably have found their way into classrooms sooner or later. But without work on PLATO, the IBM System 1500, computer-based equipment simulation, intelligent instructional systems, videodisc applications, and research on cognition, it is unlikely that the electronic revolution in education would have progressed as far and as fast as it has.**[12]

Nevertheless, there are important limitations that must be considered. First, adults, not children, are the focus of the military's training efforts. Children's needs are different. Training and education have different goals. Although skills development may have some carry-over, educational goals are more complex than the specific objectives of military training applications. Finally, although there have been civilian benefits from spinoff in technical areas, in general DoD spin-off benefiting the K-12 education community is shrinking as DoD research increasingly focuses on military applications.

As shown in table 7-1, the military's "6. 1" (basic research) budget category has remained relatively static, while funds in the "6.2" (experimental development) and "6.3" (advanced development) budget categories have grown. Furthermore, it has been suggested that less than one-third of the $25.7 million listed under 6.1 research has application to educational technology.[13] Significantly, although the amount of DoD R&D funding for instructional technology overall is considerably greater than that provided by all other agencies, no system exists to facilitate technology transfer to civilian education counterparts.[14] This continues, as it has for three decades, to be a missed opportunity.

[11] Secretary Robert S. McNamara, U.S. Department of Defense, memorandum, Aug. 16, 1965.

[12] Fletcher and Rockway, op. cit., footnote 8, p. 212.

[13] Judith Orsanu, director, Basic Research Institute, Army Research Institute, personal communication, May 1988.

[14] One official noted that one of the best, if only, mechanisms of technology transfer from the Department of Defense to civilian agencies probably comes from the fact that many researchers receive support from both sources and move freely between sponsoring agencies; Susan Chipman, personal communication, November 1987. Others have noted that informal exchange occurs more often under 6.1 funding, which typically supports university researchers, than in the case of 6.2 and 6.3 funding for applied research. These grants and contracts for experimental and applied development often go to private contractors and industry, where sharing of information is less prevalent.

Table 7-1.—Department of Defense Manpower and Training: Technology Research and Development Expenditures, 1976-87 (in millions of dollars)

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
6.1 Research	7.2	10.3	11.8	13.7	13.77	19.77	17.65	21.20	20.64	27.12	26.54	25.73
6.2 Experimental development	28.8	37.7	47.5	57.6	54.65	69.14	62.16	72.12	80.64	83.48	89.60	96.97
6.3 Advanced development	24.6	34.5	44.6	57.2	50.57	55.74	53.75	61.36	68.03	85.55	90.64	84.87
Total	60.6	82.5	103.9	128.5	118.99	144,65	133.56	154.68	169.31	196.15	206.78	207.57

SOURCE Funding levels for the years 1980-87 are supplied by the Manpower and Training Research Information System (MATRIS). The figures for 1976-79 are from the Office of the Secretary of Defense. The differences between 1979-80 may be due to some slight differences in the selection criteria and changes in program elements when MATRIS was established. The congressional categories for education and training, human factors, manpower and personnel, and simulation and training devices are included. The above figures have not been adjusted for inflation. For further detail, see Charles Blaschke et al., Education Turnkey Systems, "Support for Educational Technology R&D: The Federal Role," OTA contractor report, Sept. 30, 1987.

The National Science Foundation

NSF support has been, and continues to be, an important basis for educational technology in the schools today. Although only a small proportion of science education funds were earmarked for technology R&D at the K-12 level, this support has been critical. From 1968 to 1981, precollege technology projects received from 1 to 3 percent of NSF's science education budget. More recently, however, this proportion has changed. Since 1984, an average of 8 to 11 percent of the Science and Engineering Education (SEE) Directorate funding has supported precollege technology activities.

1968-78: The Early Years

In 1968, President Johnson issued a memorandum directing NSF to take the lead in supporting computer use in schools. NSF responded with the establishment of an Office of Computing Activities (OCA) directly responsible to the director of NSF. This high level of support was an important springboard for action. Although most of OCA's projects were at the university level,[15] 10 to 15 percent of projects supported early work in CAI and other applications of technology in elementary and secondary schools. Projects included the Huntington Two Project, to create educational materials based on computer simulations for high school biology, physics, and social studies; development of CAI materials for mathematics and reading drill and practice; and studies of the effect of CAI on teaching programming and data processing concepts to inner-city secondary school students. At this time, NSF also provided research support for a new programming language "so simple that it can be taught to second graders," which became LOGO (see box 7-B).

Support for CAI and LOGO continued when the educationally-oriented technology work moved to the newly formed SEE Directorate in 1972. New CAI projects included PLATO IV[16] and TICCIT, and the development of a computer-based high school mathematics laboratory. Much of the software for early educational computing systems came from NSF support.[17]

As the SEE Directorate suffered declining appropriations ($7 million in 1974, $5.9 million in 1975, $2.9 million in 1976), educational technology R&D support decreased as well. Nonetheless, further development, field tests, and evaluation of CAI systems continued. Other activities included support for LOGO and work on computer graphics, the development of laboratory instruments connected to microcomputers for science education, and examinations of various new telecommunication technologies for the delivery of instruction.

The decade following President Johnson's call for more research on school computer applications was an important one for educational technology despite limited funding. NSF support during this period made important and lasting contributions. Nearly

[15] These Included support of university and college regional computing networks; CONDUIT, a project supporting the transfer of computer-based learning materials and expertise across universities; and projects aimed at furthering expertise in the use of computers in specific disciplines, such as the Commission on College Physics.

[16] Over a period of 5 years, PLATO received $7.8 million in National Science Foundation funding.

[17] One analyst estimates that by 1973 over 800 of 2,750 educational software programs had been supported in part by the National Science Foundation. Beverly Hunter et al., *Learning Alternatives in U.S. Education: Where Student and Computer Meet* (Englewood Cliffs, NJ: Educational Technology Publications, 1975).

Box 7-B—The Development of LOGO

LOGO is a computer programming language designed for children. Among educational technology developments, LOGO had far reaching impact. Over two dozen versions of LOGO now exist in eight foreign language translations on 13 different types of computers. Dozens of curriculum packages and 60 books have been written on LOGO, while LOGO workshops have become a staple of preservice and inservice teacher training.

LOGO R&D received Federal support, first from the military and then the civilian sector, for more than 20 years, in spite of changing missions, budgets, and organizational structures. Researchers point to the critical role of program managers who were willing to support visionary ideas and take a long-term perspective. Projects at Massachusetts Institute of Technology (MIT) and Bolt, Beranek, and Newman (BBN) had multidisciplinary groups and collaboration among highly talented people from diverse backgrounds—developmental psychology, artificial intelligence, mathematical logic, physics, engineering, and computer science. These groups transcended traditional boundaries, even in their own institutions. At MIT, for example, the LOGO group was part of the Artificial Intelligence Laboratory which did not have a "home" in one of the traditional academic departments. Similarly, funding agents had to depart from traditional disciplinary boundaries in supporting this work.

Over the two decades of support, technology state-of-the-art changed dramatically. Each stage in LOGO's development was implemented on newer and more powerful computer systems. Researchers could take advantage of new technology capabilities at each stage because they were working in technology-rich environments that included people with expertise at the cutting edge. From the beginning, LOGO research involved work with children in classrooms. Early subjects may not have been "typical," but they provided an important connection to the real world. Currently, the Hennigan School in Boston is the site for the MIT study of the impact of LOGO microworlds in a technology intensive environment.

Chronology

1963-68: Wallace Feurzeig of BBN, contracts with the Office of Naval Research (ONR) to develop new computer systems for teaching complex concepts.

1965-66: BBN, with support from U.S. Office of Education, explores student use of TELECOMP, an interactive programming language, at eight elementary and secondary schools served by BBN time-sharing system.

1966: Feurzeig, intrigued by the results of working with children on TELECOMP, convinces ONR to let him develop a programming language for children under the ONR contract. The contract officer agrees, providing that work with children is done at a military dependents' school.

1966: Seymour Papert of MIT, Daniel Bobrow of BBN, and others work with Feurzeig on designing a procedural computer language simple enough for children to learn yet powerful enough for expressing important intellectural content. The new language, named LOGO, is based on LISP, ironically considered to be one of the most difficult of programming languages to learn.

1967: First version of LOGO used in teaching math with fifth and sixth grade students at Hanscom Field School in Lincoln, Massachusetts, with ONR support.

1968-69: LOGO-based mathematics in second, third, and seventh grades. (National Science Foundation (NSF) support for BBN was unusual since they traditionally funded only universities. But NSF became convinced that this work was important, and that only BBN could do it.)

1970-71: NSF continues support to BBN for the development of extended LOGO-based mathematics curriculum materials. LOGO-related work also funded by Air Force Office of Scientific Research on programming languages as a tool for cognitive research.

1970: BBN develops first version of LOGO for the DEC PDP-10, the computer system widely used in universities and educational research centers, and distributes it free of charge to all interested universities and research centers.

1970 to 1986: NSF continues support for LOGO at BBN, MIT, Syracuse University, New York Academy of Sciences, and other centers. But NSF support does not come easily. In the mid-1970s Science Education Directorate staff were unsure whose responsibility LOGO was: mathematics educators did not regard LOGO as true mathematics, while computer science educators did not regard it as valid computer science.

1986 to Present: Two new versions of LOGOWriter and LegoLOGO expand the scope of applications. NSF continues to fund research applications at Lesley College, Kent State University, Carnegie-Mellon University, and other institutions.

Photo credit: LOGO Systems, Inc.

Concepts in engineering, physics, and robotics are made real as students write computer programs to operate machines they have created in LegoLOGO.

all the technological tools, pedagogues, and methodologies now widely used in education had their instructional origins in these early NSF projects—telecommunications and computer networks, graphics, speech synthesis, programming languages such as LOGO, laboratory instrumentation, instructional simulations, interactive dialogs, economics modeling and gaming, social science data analysis, interactive videodiscs, career counseling systems, and computer literacy for educators.

1978 to 1988: Commitment to Educational Technology Despite Setbacks

At the time when schools were beginning to acquire microcomputers in large numbers, NSF had no program focused on educational technology R&D per se. However, from 1977-81 approximately $1.6 million per year was targeted to technology in the Research in Science Education (RISE) and Development in Science Education (DISE) Programs in the SEE Directorate. While the research sum was small, it was significant because it supported work in cognitive science and artificial intelligence applications to instruction. This was the only research of its kind being supported outside the military. NSF officials point to this early work as seminal in the field of intelligent CAI and intelligent tutoring systems.[18]

Other activities supported by RISE and DISE included the development of computer literacy materials and studies, the use of computers to teach reasoning skills to junior high students, a study of new applied mathematics techniques using the PLATO system, development of mathematical reasoning programs for young children, and development of prototype materials for interactive videodiscs.

In 1981, the SEE Directorate was dismantled, a political event which had traumatic results for the science and technology community. Research groups were disbanded; some researchers moved into industry, some to military training, and others left the field altogether. Many observers believe it created a serious hiatus from which science education is still recovering. During this period, NSF personnel who remained made creative efforts to seek alternative means of continuing support for research in educational technology.

Two approaches were adopted: industry partnerships and interagency cooperation. Neither came easily, but both produced important results. Industry partnerships were forged under the program "Development in Science Education Involving NSF/Industry Cooperation for Science and Engineering Education Using Computers. " The program encouraged universities to develop innovative prototypes of CBI materials or model programs in science and engineering education. Support was shared almost equally between NSF, industry (through donations of computer equipment), and the grantee institutions, each of whom had to provide at least one-quarter of the project cost to receive an award.[19]

The second focus was interagency cooperation. In order not to lose momentum and skilled research-

[18] Andrew R. Molnar, "intelligent Tutors and Knowledge-Based Systems in Education," paper presented at the Conference of *Applications* of Artificial Intelligence and Expert Systems, 1986.

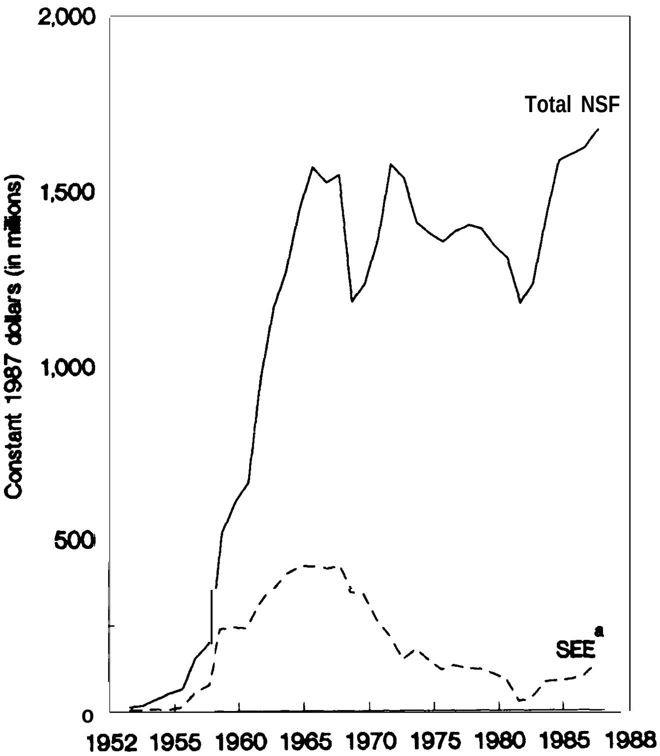
[19] Dorothy K. Deringer and Andrew R. Molnar, "University, Industry, and Federal Cooperation—A Case Study, " *Science, Technology, and Human Values,* vol. *8, No.* 4, *1983,* pp. 40-45.

ers in the middle of projects, other program offices in DoD and the Department of Education picked up some of the NSF projects. For example, NSF and the National Institute of Education (NIE) provided joint funding for research on cognitive processes that provided a basis for closer relationships between cognitive science and technology. But interagency funding has its drawbacks: it is difficult to negotiate and subject to short-term support, especially if dual funding is perceived as duplication of effort rather than cooperation. NSF took this risk because the situation was desperate and interagency finding was the only way to support important work in progress.

With the reestablishment of the SEE Directorate in 1984, R&D activity in technology expanded. Funding for science and engineering education, while not yet returned to its 1968 level, has grown (see figure 7-4). A 44 percent increase for 1988 pushed NSF's education budget to $139 million, followed by a fiscal year 1989 request of $159 million. Educational technology R&D aimed at elementary and secondary education is also receiving more emphasis, now approximately 10 percent of the SEE budget. (See figure 7-5.) Four programs sponsor activity: Instructional Materials Development, Informal Science Education, Research in Learning and Teaching, and Applications of Advanced Technologies.

Several projects in the Instructional Materials Development Program are exploring alternative methods of delivering instruction via computers, videocassettes, and telecommunication technologies.

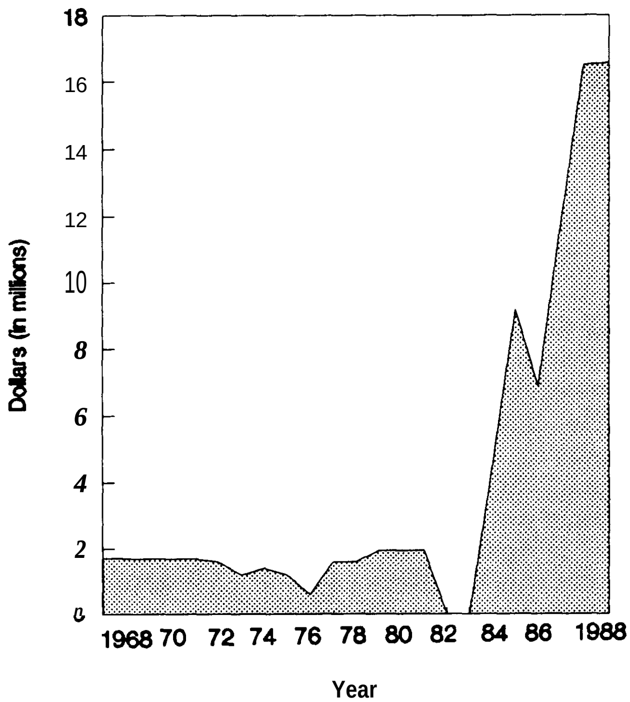
Figure 7-4.-National Science Foundation Budget, 1952-88



[a]SEE: Science and Engineering Education Directorate.

SOURCE: Michael S. Knapp et al., *Opportunities* for Strategic *Investment in K-72 Science Education: Options for the* National *Science Foundation* (Menlo Park, CA: SRI International, June 1987), vol. 2, from data supplied by NSF/SEE.

Figure 7-5.—National Science Foundation Obligations for Research and Development of Educational Technology in Elementary and Secondary Education[a]



[a]Estimates are based on the following NSF programs:

1968-71 —10°/0 of the Office of Computing Activities for elementary and secondary education

1972-76—20% of CIE and Technological Innovations in Education for elementary and secondary education

1977-76—15% of Development in Science Education and Research in Science Education

1979-61 —15°A of DISE and RISE + $333,000 joint program with NIE

1964—66-200/0 of Instructional Materials Development (IMD) + 1000/. of Advanced Applications of Technology (AAT) + $500,000/year for Research in Teaching and Learning

1987-88—NSF estimates based on IMD, AAT, and Teacher Preparation and Enhancement programs

SOURCE: Office of Technology Assessment, 1986.

The Informal Science Education Program supports several media projects, some funded jointly with the Department of Education. Television programs include *NOVA, 3-2-1 Contact!* and *Square One TV.*

The Research in Learning and Teaching Program funds several projects in cognition and studies of student difficulties in understanding concepts in science and mathematics. Computer projects include a study of the effects of computer-based curricula in school algebra; a project looking at how high school students and teachers solve problems in genetics using computer simulations; and an assessment of elementary and middle school children's LOGO debugging skills.

Examples of work supported by the Applications of Advanced Technologies include study of intelligent tutors in calculus, algebra, geometry, prealgebra, and algorithmic problem solving; creation of a computer work station for children; creation of Boxer, a new educational computing system; synthesis of research findings on key factors in science teaching and learning using instructional technology; several projects applying or extending LOGO in mathematics; and development of microcomputer-based laboratories.

Summary of NSF Impact

NSF educational technology R&D made important strides when it enjoyed periods of secure, long-term funding and when Presidential interest made it a priority. At other times herculean efforts were required to maintain and support critical research, development, demonstration, and evaluation. It took several years after the shutdown of the SEE Directorate for momentum to return. Since the first new major grants were made in 1985, results are only now beginning to percolate through the system.[20] Even with increased funding, organizational divisions inhibit the flow of research into development, and on into school demonstrations and evaluations. As one manager noted, "We fund research but have no money for development, or development with no funding for demonstration, or demonstration with no funding for field tests or evaluations."[21] It is difficult to conduct good research, to hold good Federal managers, or to attract new researchers to the field under these conditions,

Another important factor to note is that NSF's R&D has primarily influenced technology use in science and mathematics, because of NSF's mandate in these subject areas. The impact has been important for these disciplines, but educational computer applications in the humanities and arts have not benefited in equal measure. This would not be a problem if other agencies, particularly the Department of Education, were to fill in the gaps. As the next section outlines, strategic support has been lacking at the Department of Education.

Office of Education/Department of Education[22]

Education's support for educational technology spans three decades and includes efforts to develop educational television and public broadcasting facilities, to increase access to technology by enabling schools to purchase hardware and software, and to expand the base of knowledge and innovation through R&D. Support for the technology infrastructure and materials acquisition far exceeded the dollars invested in R&D.

Much of Education's finding for educational technology came from categorical programs and block grants that allowed school districts to purchase technology—televisions in the 1960s and 1970s; computers, videocassette recorders (VCRs), and software in the 1980s. Enabling schools to acquire instructional technologies creates a "bottom up" incentive for innovation and research. As the base of machines in schools grows, their use expands, driving development of new products to feed the school market. Consequently, Federal policies that encourage purchases of technology can indirectly stimulate R&D.

Education's limited spending for R&D in the area of educational technology is not surprising when one looks at the overall low priority granted education research in general. Barely half of one percent of

[20] John Walsh, "Breakthrough for Education at NSF?" *Science,* vol. 240, Apr. 15, 1988, p. 272.

[21] Andrew Molnar, National Science Foundation, personal communication, May, 1988.

[22] The Office of Education was a part of the Department of Health, Education, and Welfare until the establishment of a cabinet-level Department of Education in 1980. In this report, both organizational entities are referred to as "Education."

the Department of Education budget goes to research.[23] By comparison, the Nation spends about as much annually on health care as on education, but it spends 60 times as much on health research.[24] The military, where R&D has been increasing at an average increase of 7.8 percent per year since fiscal year 1984, devotes about 12.8 percent of its total DoD obligation to research.[25]

Of all the Federal agencies, it is most difficult to extract consistent figures on funding for educational technology from Education. Technology has been supported in various pockets of programs, often without a line item in the budget. OTA estimates that between 1961 and 1987 Education spent approximately $200 million for educational technology R&D on computer-based applications. Although a sizable total investment, given the 26-year time span, it is in fact small from the perspective of overall Federal R&D in this area. (DoD instructional technology R&D expenditures from 1971 to 1987, a 16-year time period, is over $1.9 billion.) In fact, each *year* the military spends approximately as much for R&D in educational technology as the Department has over the last 26 years.

Early Efforts

Education's largest investment in technology has been in support of public television, both through the creation of the public broadcasting infrastructure and in television programming that addresses critical educational needs. The American public and the schools are still enjoying the fruits of this investment. The Educational Broadcasting Facilities Program was created by Congress in 1962 to assist (through matching grants) in the construction of noncommercial educational television or radio broadcasting facilities. Between 1962 and 1978, when the program was transferred to the Department of Commerce, Education spent a total of $151 million on public broadcast facilities. Television and radio programming support began in 1968 with support to the Children's Television Workshop for R&D on *Sesame Street,* and continued with funds provided by the Emergency School Aid Act (ESAA), passed in 1972 to eliminate minority group segregation and discrimination. One of the activities supported by the act was the development and production of integrated children's television programs of cognitive and affective value. ESAA funds provided a total of $67 million for television series and related activities, including such series as *Villa Allegre, Vegetable Soup,* and *Infinity Factory.* Funding for television programming from 1968 to 1980 totaled $134.3 million.[26]

One of the most important changes in the Federal funding of education was the 1965 passage of the Elementary and Secondary Education Act, which focused national attention on education and provided increased financial support.[27] The "War on Poverty" looked to education as a means of creating social change, and computer-based education was seen as a potentially powerful tool for improving the educational opportunities for the disadvantaged. Time-sharing on mainframes made it economically feasible for students to begin to have access to expensive computers.

One of the best known computer-related projects supported by the Office of Education in the 1960s was Stanford University's development of instructional materials for educationally disadvantaged elementary school children. The Stanford computers in California were able to serve students as far away

[23] "This is of special concern since the Federal Government is the primary source of funding for such research, as there is no education industry investing in educational research as we find in other areas." Nancy Cole, president, American Educational Research Association, testimony before the House Committee on Education and Labor, Subcommittee on Select Education, Apr. 21, 1988.

[24] Institute for Research on Learning, *The Advancement of Learning* (Palo Alto, CA: 1988), p. 11. The expenditure on health services for 1987 is estimated at $496.6 billion in "National Health Care Expenditures, 1986-2000," in *Health Cam Financing Review*, summer 1987, p. 24. The 1987 expenditure on health research by the Department of Health and Human Services is from the 1989 fiscal year budget. Total spending on education and training at all levels is estimated at $453 billion ($ 144 billion at the elementary and secondary level, $94 billion for post-secondary, $210 billion for employee formal and informal training, and $5 billion for government training); see Anthony Carnevale, American Society of Training and Development, "The Learning Enterprise," *Training and Development Journal*, January 1986, p. 18.

[25] Richard E. Rowberg, chief, Science Policy Research Division, Congressional Research Service, testimony before the House Committee on Education and Labor, Subcommittee on Select Education, Apr. 21, 1988.

[26] Andrew A. Zucker, "Support of Educational Technology by the U.S. Department of Education: 1971 -1980," *Journal of Educational Technology Systems, vol. 10, No. 4, 1981-82,* pp. 303-320. Department of Education staff indicate that an additional $25 million was spent on educational television since 1980. Arthur Sheekey, Office of Educational Research and Improvement, U.S. Department of Education, personal communication.

[27] Overall Federal funding for education increased from $375 million in **1958** to $4.2 billion in 1968.

as Kentucky and Mississippi via telecommunications—itself a powerful demonstration of technology. An unusual financial feature of the project was the use of Title III funds, which were awarded to States and localities for services, to supplement the direct support made available to Stanford for R&D.

During the 1960s, the Office of Education also funded several significant R&D projects involving video technology, including evaluation research comparing conventional teaching and video presentations; the establishment of a video clearinghouse, the National Instructional Television Center at Indiana University, from which grew the current Agency for instructional Television (now the Agency for Instructional Technology); and support for improved capacity of public radio and television stations under the Education Broadcast Facilities Program. In 1964, NIE funded the Learning Research and Development Center (LRDC) at the University of Pittsburgh. One of LRDC's mandates was to study the potential of technology for education.

The 1970s: Educational Television, Special Education, and CAI Evaluation

In the 1970s, much of R&D continued to focus on television as an educational tool, Education also spent approximately $200 million on computer-related activities during the 1970s, of which about $50 million was for R&D, including demonstration projects. Many significant R&D projects in the Bureau of Education for the Handicapped opened new learning opportunities for the handicapped. These projects included closed captioning of television, enabling the deaf to have access to a substantial portion of television programming for the first time; development of the OPTACON for the blind, a device which produces images of printed letters using small, raised, vibrating wires; and support for the development of the Kurzweil reading machine, another device for the blind, which scans text and reads text aloud through synthesized voice technology. Subsequent funding supported dissemination of these devices. The Bureau of Education for the Handicapped also supported a computerized database on instructional materials for the handicapped; studies of reading and mathematics CAI materials for deaf and hearing impaired students; and demonstrations of electronic mail for communication with the deaf.

Other technology programs during this period included several applications of telecommunications for education: the Educational Telecommunications for Alaska project, which provided the scattered and small Alaskan schools with electronic mail, CAI, and other services via microcomputers; and the Appalachian Community Service Network, which used satellite distribution of instructional programming.

Research on the effectiveness of CBI, as well as development and evaluation of computer software was also begun. Projects included an extensive 5-year longitudinal study of the effectiveness of CAI in the Los Angeles public schools, conducted by the Educational Testing Service; an educational software review and distribution service for school districts (MicroSIFT) under contract to the Northwest Regional Laboratory; and development of software in mathematics (Ohio State University), writing (Bolt, Berenek & Newman), and language arts (WICAT). Products created by these software development projects were made available for commercial distribution and were used by schools. In addition, development of a multimedia science and mathematics program series for children that included broadcast television, computer software, and videodisc materials was funded through a multiyear award to the Bank Street College of Education for the creation of the *Voyage of the Mimi.*[28]

Early 1980s: Block Grants, Computers, and a Technology Initiative

As computers became widely available, there was great excitement surrounding them; *Time* magazine chose the personal computer as "Man of the Year" for 1982. Schools no longer had to purchase large, expensive systems in order to use computer technology; they could buy as many or as few computers as they could afford. Parent-Teacher Associations bought them for schools as fast as bake sale proceeds came in. Federal Chapter 2 funds also became an important resource.[29]

[28]additional funding was provided by the National Science Foundation in subsequent years. This was due in part to efforts by Department of Education program managers who, recognizing the need for additional funding beyond Department of Education allocation, turned to their colleagues in the National Science Foundation for help.

[29]The Education Consolidation and Improvement Act of 1981 consolidated discretionary grant programs into block grants that were directed to the States and local jurisdictions through formula fund-

(continued next page)

Where separate authorizing legislation existed, and where program managers had a commitment to technology, the Department continued to fund technology R&D activities.[30] From 1981 to 1987, an estimated $129 million was spent on educational technology R&D and demonstration projects with computers.[31] The Office of Special Education and Rehabilitative Services continued studies of computer use for handicapped students, with followup projects that developed a variety of applications including hardware, adaptive devices, and special education software. Dissemination efforts were designed to bring research findings and development efforts to schools and the special education community. Additional studies were conducted in the Office of Vocational and Adult Education and in NIE, but most were not given adequate support to move beyond research into development, classroom trial and evaluation, and dissemination, particularly after a shift in Department research priorities after 1984.

The Department of Education began its participation in the congressionally-mandated Small Business Innovation Research (SBIR) Program in 1983. The SBIR Program is aimed at accelerating the commercialization of new devices developed under government support. With funding levels that are based on a percentage of the agency's overall external R&D budget, SBIR grants were awarded for technological innovation in areas proposed by the Offices of Special Education, Vocational Education, and Educational Research.

Several computer projects were supported by the Department of Education in the early 1980s under the Secretary's "Technology Initiative."[32] Although not a new funding initiative, this effort signaled Secretary Bell's support for technology through a variety of programs under existing authorities within the Office of Educational Research and Improvement (OERI). Among these were 12 technology demonstration projects where computer applications were studied and showcased; studies of the availability and quality of software in reading, mathematics, sciences, and foreign languages; and continuing support for *The Voyage of the Mimi* television series and accompanying computer materials, and for two other educational television series, *3-2-1 Contact* and *Spaces*.

The Department sponsored a research conference in November 1982 on the potential of computers for education.[33] Recommendations made by the distinguished group of experts from the fields of artificial intelligence, cognitive science, and education provided a conceptual framework for the Depart-

(continued from previous page)

ing. These funds (Chapter 2), distributed on the basis of the number of students, were to be used for educational improvements as the States and districts saw fit. Many districts used their block grant monies to purchase computer hardware and software. Chapter 2 and its predecessor programs have provided about $510 million for computers and related expenditures. A study of the Chapter 2 block grant program showed that, for the third year of block grants (1984-85), support for computer applications was the most popular activity, accounting for 30 percent of all local expenditures under block grants. During this same period, 72 percent of the Nation's schools used Chapter 2 for computer-related purchases. Michael S. Knapp et al., *The Education Block Grant at the Local Level: The Implementation of Chapter 2 of the Education Consolidation and Improvement Act in Districts and Schools* (Menlo Park, CA: SRI International, January 1986).

[30]For a full list of these projects, see Susan Klein, *Computer Education: A Catalog of Projects Sponsored by the U.S. Department of Education* (Washington, DC: U.S. Department of Education, 1983). One example was the Title VII 3-year grant awarded to the Seattle Public Schools to develop computer-assisted instruction in U.S. history for Vietnamese, Cambodian, and Laotian high school students. See U.S. Congress, Office of Technology Assessment, "Trends and Status of Computers in Schools: Use in Chapter 1 Programs and Use With Limited English Proficient Students," staff paper, March 1987, pp. 86-87, box B.

[31]OTA extrapolation, based on Klein, op. cit., footnote 30.

[32]U.S. Department of Education, "Fourth Update on Technology Initiative Activities," internal memorandum, Jan. 18, 1984.

[33]Alan Lesgold and Frederick Reif, *Computers in Education: Realizing the Potential*, Report of a Research Conference (Washington, DC: U.S. Department of Education, August 1983).

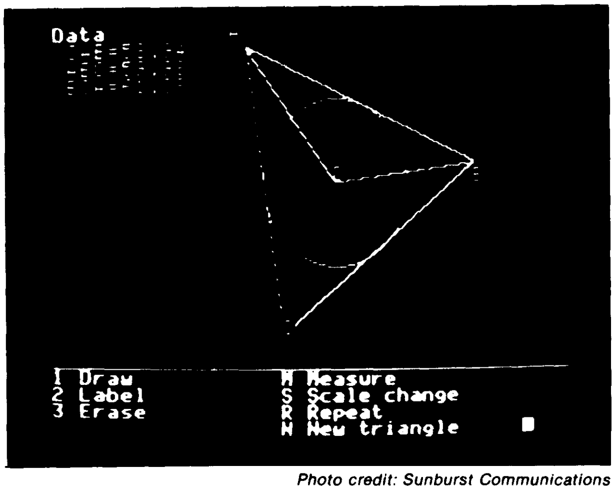


Photo credit: Sunburst Communications

In the *Geometric Supposer*, developed with Federal funds, students can manipulate geometric shapes to test and apply theorems.

ment's technology research agenda, and were included in planning the competition for a Department-sponsored Educational Technology Center. A nationwide competition for the center was held, and the award was made to the Harvard Graduate School of Education, funded at $7.7 million over 5 years to conduct R&D on the role of technology in teaching mathematics, science, and computing. The center focused on "targets of difficulty," curricular topics that are both critical to students' further progress in these fields, and widely recognized as difficult concepts to teach and learn. Various research projects at the center studied the nature of students' difficulties in understanding, exploited the educational capabilities offered by computer-based technology, and designed experimental lessons using computers as well as traditional materials to address these difficult topics. Teams made up of researchers from the center and participating classroom teachers tried out some of these promising units in local high schools to learn how they worked in the classroom.[34]

As part of a plan to increase Department of Education involvement in educational technology, Secretary Bell created a National Task Force on Technology in 1983, ". . . to investigate the potential of appropriately integrated technology to improve learning in our nation's schools."[35] It was Bell's hope that this Task Force would set a national agenda for educational technology.

1984 to Present: A Lower Priority for Technology

When Secretary Bell left the Department of Education in 1984, the technology initiative and related emphasis on computer activities ground to a near halt. The new Secretary, William Bennett, did not share Bell's vision of improving education through technology. The climate in the Department, reflected partly in the declining number of new grants involving computers, shifted significantly.

Illustrative of Bennett's lack of interest in technology is the Department's response to *Transforming American Education: Reducing the Risk to The Nation,* the report to the Secretary by the National Task Force on Educational Technology, referred to above. Unlike *A Nation At Risk,* which was released at a special ceremony at the White House and given major nationwide distribution and publicity, the technology report was held several months and eventually released but not printed or made available to the public through the normal Government Printing Office channels.

The reductions in computer-related R&D were especially notable in the obligations of OERI, which was not bound by the legislative mandates as is the case in the Office of Special Education[36] or the Office of Post-Secondary Education. OERI, which took over the National Institute of Education in 1984, has a more open charter and is therefore more responsive to general priorities in elementary/secondary education established by the Secretary and Assistant Secretary. The trend is displayed in several ways. A recent computer printout listing OERI technology projects supported since 1980 illustrates how many were supported in the early 1980s and how many fewer have been started since 1983.[37] Another change is in support for R&D projects of long duration. In the 1970s, the Department supported quite a few projects lasting 5 or more years (e.g., the longitudinal study of CAI in Los Angeles, development of closed captioning of television, the Kurzweil reader, and the *OPTACON).* During the 1980s, few projects received comparable long-term support. Finally, the number of research grants to individual researchers decreased substantially.[38] While this decrease affected educational research as a whole, projects with a technology orientation were particularly notable by their absence.[39]

Summary of Department of Education's Impact

The Department of Education has had an off and on love affair with technology. Where research support has been consistent, as in support of children's

[34] Educational Technology Center, Harvard Graduate School of Education, "Making Sense of the Future," a position paper on the role of technology in science, mathematics, and computing education, January 1988, p. 1.

[35] National Task Force on Educational Technology, "Transforming American Education: Reducing Risk to the Nation," a report to the Secretary of Education, unpublished manuscript, April 1986.

[36] A detailed discussion of the various programs and projects for the handicapped and others with special needs can be found in Blaschke et al., op. cit., footnote 5.

[37] Sheekey, op. cit., footnote 26.

[38] General Accounting Office, op. cit., footnote 3.

[39] Of the nine grants to Field-Initiated Research Studies funded in fiscal year 1987, one had a technology focus. Sally Kilgore, director, Office of Research, Department of Education, letter to colleagues, May 13, 1988.

television programming in the late 1960s through the 1970s, or long term as in support for technology in special education, important milestones were reached. These are the exceptions. Most research projects did not have opportunities to proceed from laboratory research through to development of products and processes, much less to testing in the classroom, with real students and teachers.

Other Agency Support for Educational Technology R&D

Other Federal agencies have also supported research that has or could ultimately lead to innovations in education. The National Institutes of Health supports medical research that includes studies on the brain and the way it functions. The Department of Labor has numerous manpower training and retraining programs that use technology to help workers enter the labor force or to adjust to changes in required job skills. The State Department and the Agency for International Development have language and other training programs and have applied computer-based technologies to improve these education activities. The National Aeronautics and Space Administration (NASA) spends approximatley $8 million a year in artificial intelligence research; R&D on human-machine interfaces in the areas of vehicle control and space station applications are

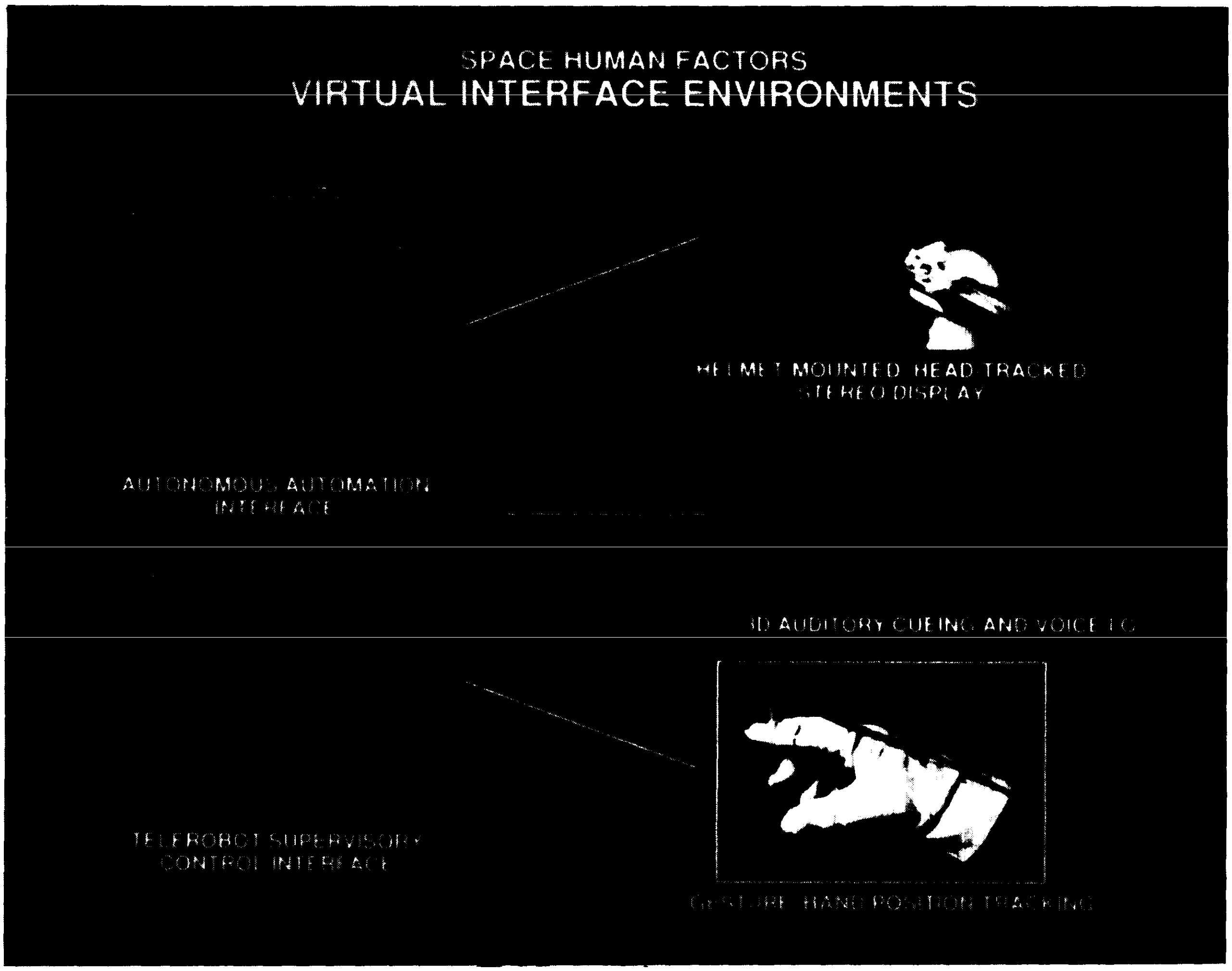


Photo credit: National Aeronautics and Space Administration, Ames Research Center

How can technology research conducted by other Federal agencies be applied to benefit education?

in addition to this funding[40] (see box 7-C). NASA also has an extensive education program in astronomy and space sciences, and has developed software and videodisc materials for schools, and satellite broadcasts and telelectures for teacher education.[41]

These and other government-supported R&D programs contribute information and innovations to the area of educational technology, but it is difficult to identify the most promising projects for education or to measure the cumulative level of funding or impact. Project goals and priorities are targeted to each agency's mission, and are not generally considered for potential applications in schools. Typically, these agencies share a common problem with the Department of Education, NSF, and DoD—the lack of enthusiasm or support for technology transfer within programs in house or across agencies.

[40] Melvin D. Montemerlo, Office of Aeronautics Space Technology, Division of Information Sciences and Human Factors, National Aeronautics and Space Administration, personal communication, March 1988.

[41] National Aeronautics and Space Administration, Educational Affairs Division, Office of External Relations, *Educational Affairs Plan: A Five-Year Strategy FY* 1988-1992 (Washington, DC: October 1987).

Box 7-C.--NASA's Intelligent Computer. Aided Training: Spinoff for Schools

At the Johnson Space Center, NASA researchers are conducting research in the area of expert systems in advanced physics and astronomy for use in flight training modules. They are also developing a tutoring system using CLIPS, an authoring language which subject matter specialists can use to write their own tutoring programs. Both these projects have applications for education, and the researchers at NASA are looking for ways to share their findings with the Texas schools. Because NASA has a technology utilization program whose mandate is to encourage technology transfer to civilian and industrial programs, there is funding to facilitate this research spinoff to schools. The projected cost of applying the research toward the development and school-based testing of a high school physics course which uses intelligent tutoring software is approximately $1.3 million.

CURRENT FEDERAL PRIORITIES

Although the military, through DARPA, ONR, and the Service laboratories, has been a major contributor to basic research in technologies that have later led to educational developments, both Federal officials and researchers suggest that this may no longer be the case. Overall funding for basic research in DoD has received a smaller share of the Defense R&D budget as big ticket items falling into the 6.2 and 6.3 categories of exploratory and advanced development take a bigger bite (see table 7-2). Furthermore, present research priorities preclude projects in cognitive science that have an education, rather than training, orientation. Many fear that the pipeline for innovative developments for education will suffer from the lack of support from a once powerful funding patron, the military R&D agencies.

Educational technology research at NSF, however, is on the upswing. As shown in table 7-3, the fiscal year 1989 budget request for precollege technology efforts is 61 percent higher than that for fiscal year 1987. As noted above, however, NSF's focus is predominantly on mathematics, science, and computer programming. The Department of Education, which has responsibility for research in broader areas related to education, has just recently begun to again target limited spending on technology (see table 7-4 and appendix C). In a recent Department of Education informal survey asking education researchers to list the areas of education research most likely

Table 7-2.—Department of Defense Research and Development Funding, 1984-89[a] (in billions of dollars)

	Fiscal year					
	1984	1985	1986	1987	1988	1989[b]
Research , , .,	0.84	0.85	0.95	0.89	0.90	0.92
Exploratory development,	2.22	2.27	2.28	2.34	2.39	2,36
Advanced development[c].,	1.41	2.70	4,07	5,03	5.43	6,51
(SDI) , .,,,....	(0.05)	(1.39)	(2.66)	(3.26)	(3,53)	(4.52)
Other ., ...	22.27	25.28	26.20	27,82	29.17	29,09
Total. ., . .	26.76	31.10	33.50	36.09	37.90	38.87

[a] Data provided by the Office of the Secretary of Defense.
[b] Current administration request.
[c] Includes funding for the Strategic Defense Initiative (SDI).

SOURCE: Richard Rowberg, Chief, Science Policy Research Division, Congressional Research Service, testimony before the House Committee on Education and Labor, Subcommittee on Select Education, Apr 21, 1988.

Table 7.3.–NSF Funding for Educational Technology Research and Development, 1987-89 (In millions of dollars)

	Fiscal year		
NSF program	1987	1988 (est.)	1989 (est.)
instructional materials development	4.1	7.4	9.0
Applications for advanced technology	5.2	5.6	6.0
Teacher preparation and enhancement	2.5	3.5	4.1
Total technology	11.8	16.5	19.1
Total precollege	60.0	83.0	97.0

[a] Funds from the Teacher Preparation and Enhancement Division that were used for technology are estimates. The amount is difficult to separate from other activities.
[b] Does not include the budget for informal education and major broadcast projects, totaling approximately $7 million in fiscal year 1987.

SOURCE: Office of Technology Assessment, based on data from the National Science Foundation, 1988.

to produce significant breakthroughs and the greatest impact on practice during the next 5 years, "computers in the classroom" tied for third most frequently mentioned. Assistant Secretary for Educational Research and Improvement, Chester Finn, summarized the educators' comments on this breakthrough area:

> The computer will deepen its presence in schools and classrooms as software improves and teachers begin to see it as a powerful tool for getting the job done. The microcomputer offers more information than any teacher can, and it puts that information directly into students' hands, permitting them to interact with it—to manipulate graphs, enact simulations, edit texts. Eventually, a keyboard will be at the fingertips of every student in every class.[42]

[42] Chester Finn, "What Ails Education Research," *Educational Researcher, vol. 27, No.* 1, pp. 7-8, January/February 1988.

Table 7-4.—Department of Education Funding for Educational Technology Research, Development, and Demonstration, 1987-89[a]

	1987		1988		1989	
Office of Educational Research and Improvement (OERI):						
Regional educational laboratories[b]	$1,808,798	(EO)	$ 1,225,926	(EO)	$1,148,456	(EO)
National research and development centers[c]	1,000,000	(EO)	1,000,000	(EO)	Pending	
Educational technology center	2,000,000	(0)	900,000	(0)	1,000,000	(EO)
Field-initiated research grants	62,508	(0)	unknown		unknown	
Programs of national significance:						
Technology awards under science and mathematics, and critical foreign languages discretionary funds competition[d]	530,000	(0)	970,000	(EO)	unknown	
Technology competition	-0-		1,000,000	(EO)	unknown	
Educational television	3,250,000	(0)	2,225,000	(EO)[e]	unknown	
Small Business Innovative Research	1,700,000	(0)	1,700,000	(EO)	1,700,000	(EO)
ERIC Clearinghouse on Educational Technology	288,000	(0)	298,283	(0)	unknown	
National Diffusion Network—technology projects	310,000	(0)	150,000	(EO)	unknown	
Star Schools	—		19,148,000	(A)	-0-	
Special education:						
Technology for special education	4,670,000	(A)	4,790,000	(A)	4,790,000	(R)
Personnel development	2,290,000	(EO)	1,810,000	(EO)	1,270,000	(EO)
Early childhood education	-0-		-o-		300,000	(R)
Vocational education:						
Research center-technology projects	192,091	(EO)	unknown		unknown	
High technology demonstrations	-0-		9,600,000	(EO)	9,600,000	(EO)
Adult education:						
Job Skills Education Program	-o-		128,000	(0)	unknown	

Abbreviations: O: Obligation; EO: Estimated Obligation; A: Appropriation; R: Budget Request

[a] Other programs support technology demonstrations and applications, but there is no information available to document funding related to technology. These include: the Magnet Schools Assistance Act (Title Iii, Education for Economic Security Act—EESA), the Bilingual Education Act (Title VII, EESA, Parts B and C), and three programs authorized under the Higher Education Act (the Fund for improvement of Postsecondary Education, HEA X-A; Leadership in Educational Administration Development, HEA V-C-2; and the Christa McAuliffe Fellowships, HEA V-D-2). Formula funding programs also support technology. These include: Chapter 1, Economic Consolidation and improvement Act—ECIA; Chapter 2 (ECIA); EESA, "Mathematics/Science Program; the Bilingual Education Act (Part A, State and local grants); the Education for the Handicapped Act (State grants); and the Carl D. Perkins Vocational Education Act (Title Ii). With the exception of Chapter 2 block grants, information to document activities related to technology is not available. An estimated 30 percent of appropriations for Chapter 2 block grants is used for technology applications.

[b] Nine regional educational laboratories carry out applied research and development and provide technical assistance within multistate regions. The total annual appropriation is $17 million for 1987, 1988, and 19S9. Funding for educational technology activities comes from OERi grants and other sources. Additional funds for technology were provided to the laboratories through the Rural Education initiative (Education Appropriations Act of 1986) which appropriated $4 million over 2 years and gives a priority to applications of technology. The amounts shown include only Federal funding.

[c] Nineteen centers conduct research on educational topics of national significance over a 3 to 5 year period. The total annual appropriation has been $17.5 million since 19S5. Center awards range from S500,000 to $1.2 million annually. One center has designated responsibility for educational technology R&D, but several others support research projects that have a strong technology component. Some centers support research that may lead to future applications of technology for learning.

[d] Includes critical foreign language projects involving technology, which account for approximately 10 percent of critical foreign language discretionary funds,

[e] Includes $1 million for *Square* One TV, currently under review.

SOURCE: Office of Technology Assessment, based on data from the U.S. Department of Education, *The Fiscal Year 1989 Budget,* Summary *and Background /formation* (Washington, DC: U.S. Department of Education, February 1988); personai communication and lists of Departments of Education grants and awards, April 1988.

A new technology competition under the Programs of National Significance in the Title II Program for Mathematics, Science, Computer Education, and Critical Foreign Languages will have a funding level of $1 million. There is also a new competition for an Educational Technology Center. However, the RFP calls for less support ($5 million over 5 years, versus $7.7 million from 1983 to 1988 under the current contract) with a much broader research agenda. The new center will be responsible for all curriculum areas, not just mathematics and science, and its mandate will cover not only technology, but also teaching, learning, assessment, and school leadership. Despite the limited budget, interest in the center competition has been very strong. Indeed, the new technology center is perceived as "the only game in town" by the educational technology research community.

No new educational television initiatives are planned, and although the new congressionally mandated Star Schools Program for distance learning projects is authorized at a level of $19.1 million for 1988, no funds are requested in the Department's 1989 budget.

OTA concludes that these efforts fall short of focused, long-term commitments called for by the National Governors' Association, the National Task Force on Educational Technology, and the National School Boards Association.[43]

[43] See National Governors' Association, Center for Policy Research and Analysis, *Time for Results: The Governors' 1991 Report on Education* (Washington, DC: 1986); National Task Force on Educational Technology, op. cit., footnote 35; and National School Boards Association, *A National Imperative: Educating for the 21st Century* (Alexandria, VA: 1988).

PROMISING DIRECTIONS FOR RESEARCH[44]

OTA finds that both recent research results and current demands for change in schools make increased research on technology and education especially promising at this time.[45] Three major factors make this so:

1. **The technology makes possible the testing and trying of new ideas. Some of the best and the brightest scientists and researchers today see education as an important frontier for research because of the potential offered by interactive technologies.[46] Work in psychology, computer science, and artificial intelligence is contributing to understanding coherent theories of how people think and learn.** These theories can now be tested on powerful computers.[47]
2. **Experimentation at all levels is leading to new uses of technology and demands for increased capabilities. As the installed base of technology** in the schools grows and becomes more powerful, new applications will become possible. Administrators want the technology to be used, and publishers want to exploit markets. As teachers become more sophisticated users of technology, they will demand better products.
3. **Critical educational needs are not being met.** The American public is painfully aware that too many students are dropping out of school, test scores are declining in relation to those of students in other industrial nations, industry is demanding a more skilled and technologically

[44] Much of this discussion comes from Roy D. Pea and Elliot Soloway, "Mechanisms for Facilitating a Vital and Dynamic Education System: Fundamental Roles for Education Science and Technology," OTA contractor report, December 1987.

[45] See Dean Brown et al., "Influences on Development and Innovation in Educational Technology, " OTA contractor report, October 1987. Both this report and Pea and Soloway, ibid., draw heavily on research documents, and personal and written interviews with preeminent researchers in the field. For a complete bibliography, see the contractor reports.

[46] Alan Collins, Bolt, Beranek and Newman, Inc., personal communication, December 1987. For example, Xerox has sponsored, with $5 million in startup funds, an Institute for Research on Learning. One of the goals of the Institute is ". . . to forge a synthesis of technology and learning theory so that the instructional capacity of new tools can be exploited. " From Institute for Research on Learning, op. cit., footnote 24.

[47] "The ability of today's scientists to model the mind on computers was made possible by generations of psychologists who watched and recorded people at work on mental tasks of all sorts, and by the accumulated efforts of artificial intelligence researchers who have been trying to understand the nature of intelligence for over 30 years. Researchers, finding thousands of regularities in the mind's handling mental tasks, are now using the computer to try to assemble those regularities into a larger picture of how the mind performs. " David L. Wheeler, "From Years of Work in Psychology and Computer Science, Scientists Build Theories of Thinking and Learning," *The Chronicle of Higher Education*, Mar. 9, 1988, p. A4.

competent work force, and the number of difficult to teach students (special education students, non-English speaking students, and those from homes where educational support is lacking) is increasing. These problems, coupled with a shortage of teachers in some locations and subject areas, and growing concern over whether we can produce and keep the most talented teachers, all create a demand for change and for a more productive system for schooling.

Research in the cognitive, social, instructional, and computational sciences is changing the understanding of learning and teaching. This different focus is important—education viewed from the learner's perspective, not from the traditional curriculum/ subject matter perspective (see box 7-D).

Some of the areas where current research shows promise for educational applications include the development of intelligent tutoring systems, tools which act as intelligence extenders, microworlds for learning, multimedia learning systems, new measures of testing learning, and research on how technology affects teaching and the social structure of schools (see table 7-5).

Intelligent Tutoring Systems

Much of the research on human learning and effective teaching has been channeled into developing artificial intelligence technologies that could simulate human tutoring. There is no question that human tutoring produces the most effective learning. For example, one researcher found that only 11 hours of individual tutoring produced the same level of mastery of the LISP programming language as 43 hours of traditional classroom instruction with supplementary student homework. What is also obvious is the prohibitive expense of one-on-one tutoring. The technological opportunity lies in the potential applications of artificial intelligence in simulating human tutoring.[48]

Cognitive science research is focusing on those aspects of human learning that could be used to develop intelligent tutoring systems. Work supported by the Personnel and Training Research Program at ONR indicates these include:[49]

- understanding how novices and experts solve problems in order to create an "ideal student" model;
- understanding where misconceptions occur when a real student does not perform as the "ideal student" would;

[48] Susan F. Chipman et al., "Personnel and Training Research Program: Cognitive Science at ONR," *Naval Research Reviews*, vol. 38, 1986, p. 14.

[49] Ibid., pp. 15-16.

Box 7-D.--Guided Discovery: Teaching From a Learner's Level of Understanding

The learner-centered approach looks at the learner's prior level of understanding, how preconceptions or misconceptions from earlier formal or informal experience may affect understanding, and where conceptual stumbling blocks exist. Recent research has focused on diagnosing the understanding, preconceptions, and interests a learner brings to formal instruction, so that additional instruction can build upon this base and deal with specific areas of difficulty.

Studies of how students learn science illustrate this approach. Students' preconceptions about concepts such as light, gravity, motion, heat and temperature, weight and density, and other physical phenomena are being examined. The Educational Technology Center at Harvard has identified "targets of difficulty," curricular topics both critical to students' further progress in science and widely recognized as difficult to teach and learn. For example, in the Weight/Density Project, the research group began by analyzing students' beginning conceptions. Although most middle school students do not know what density means, they do have related ideas about "heaviness for size" and what makes some objects sink or float. Most youngsters have one undifferentiated concept for thinking about weight v. density where physicists require two. The distinction physicists make is hard to teach because an object's density, unlike its weight, is not directly observable. The researchers are therefore exploring the use of interactive computer models to help students observe density in a simulated environment they can manipulate and explore. These activities are combined with hands-on activities with objects of different weights, sizes, and densities, along with problems posed by teachers to guide the students as they consider the connections between their experiences with real materials and the computer representations.[1]

[1] Educational Technology #rim, HarvardCraduate~~10{~-cation, "Making Sense of the Future," a position paper on the role of technology in science, mathematics, and computing education, January 19ss, pp. 7-s.

Table 7-5.—Promising Directions for Research: Selected Examples of Intelligent Tutoring Systems, Intelligence Extenders, Complex Microworlds, and Multimedia Learning Environments in K-12 Education

Project[a]	Topic	Grade level	Institution	Funding source
Algebra Workbench	Early algebra instruction using LOGO.	Sixth grade	Lesley College Bolt, Berenak & Newman (BBN)	NSF
Boxer	Programming environments for educators, students, and others	Middle school to adult	University of California, Berkeley (earlier MIT)	NSF
Chips	Tool kit to create graphics intensive programs.	Designers of instructional software	Learning, Research and Development Center (LRDC)	DoD
CMU Tutor	Authoring language to create instructional programs that help diagnose student responses.	Educators and instructional designers	Carnegie-Mellon University (CMU)	NSF
Debuggy	Uses artificial intelligence and cognitive theory to diagnose subtraction errors.	Elementary school	Xerox PARC (earlier BBN)	DoD
Earth Lab	Collaborative learning and experiments in earth science using LANs,	Sixth grade	Bank Street College	NSF
Geometric Supposer	Hypothesis exploration in plane geometry,	Middle school	Harvard University Educational Technology Center	ED
Geometry Tutor	Uses cognitive theory to diagnose student errors in creating geometry proofs,	Tenth grade	CMU	NSF DoD Carnegie Foundation
Green Globs	Uses games and multiple representations to foster understanding of relationship between algebraic functions and graphs,	Middle school	University of Illinois	ED NSF
Heat and Temperatures	Helps students understand heat and temperature through microcomputer lab activities with dynamic visual representations.	Ninth grade	Harvard University, Educational Technology Center	ED
IDEA	Helps students learn to use systematic decision methods to solve problems.	Middle school to adult	New York University	Spencer Foundation
Inquire	Tool programs for active investigation of scientific phenomena.	Middle school	Bank Street College	NSF
INTERMEDIA	Hypermedia environment to create programs linking images, text, and other representations,	Undergraduate	Brown University	Annenberg Apple
Kids Network	Collaborative science experiments using telecommunications networks,	Fourth-sixth grade	Technical Education Resource Centers (TERC) National Geographic Society (NGS)	NSF NGS
LegoLOGO	Children control Lego machines using the LOGO programming language.	Elementary school and up	MIT BBN	DoD NSF
LISP Tutor	Intelligent tutoring system that provides instruction on introductory LISP programming.	High school and up	CMU	DoD
LOGO	Introductory programming language	Elementary school and up	MIT BBN	DoD NSF
Macro-contexts	Uses interactive video technologies to provide functional contexts for science learning.	Middle school	Vanderbilt University	IBM DoD
Micro-computer-based laboratory	Inquiry-oriented science tools that connect data collection hardware to graphing software	Elementary school and up	TERC	NSF ED
Modeling	Computer-based tools that let students build models of systems to learn calculus,	Tenth grade	TERC Lesley College	NSF
PALENQUE	Prototype using digital-video interactive technology that lets user "explore" a Mayan archeological site.	Elementary school	Bank Street College	GE/RCA
Proust	Diagnoses bugs in students' Pascal programs.	Middle school and up	Yale University	DoD
QUEST	A simulation environment for teaching basic electrical theory,	High school	BBN	DoD
Quill	A set of computer-based writing activities that use real documents to teach writing skills.	Elementary school	BBN	ED

(continued on next page)

Table 7-5.—Promising Directions for Research: Selected Examples of intelligent Tutoring Systems, intelligence Extenders, Complex Microworlds, and Multimedia Learning Environments in K-12 Education—Continued

Project[a]	Topic	Grade level	Institution	Funding source
Rat	Microworlds that allow children to interact with representations of everyday objects to learn basic arithmetic concepts.	Elementary school	LRDC	NSF
Reasoning under uncertainty	Introductory statistical reasoning.	High school	BBN	NSF
Sketch	Tutor to help teach graphing of simple algebraic expressions.	Middle school and up	Carnegie-Mellon University	NSF
Smithtown	Discovery world using simulations to teach macroeconomics.	High school and up	LRDC	DoD
SOPHIE	Electronic troubleshooting skills.	High school and up	Xerox PARC (earlier BBN)	DoD
STEAMER	Uses simulation to teach about operation of a steam propulsion power plant.	Vocational training	BBN	DoD
Tinker Tools	Uses game format to help learn basic concepts in Newtonian mechanics (mass, energy, and velocity).	Sixth grade	BBN	NSF
Vivarium	Computer-based models for ecology.	Elementary	MIT Los Angeles elementary school	Apple
Voyage of the Mimi	Uses multimedia materials for informal and classroom-based learning of mathematics and science.	Fourth grade and up	Bank Street College	ED NSF CBS Sony
West	Employs the coaching paradigm and a computer game format to teach basic arithmetic skills.	Elementary	BBN	DoD
Word Learning	System that helps children learn the meaning of words by providing different characterizations of the meaning of words in a passage.	Elementary school and up	Princeton University	DoD Spencer Foundation
Word Problems	Prototype using multiple representations to help students learn about reasoning with intensive quantities.	Elementary	Harvard University Educational Technology Center	ED

Abbreviations: NSF = National Science Foundation, DoD = U.S. Department of Defense, ED = U.S. Department of Education, GE = General Electric, MIT = Massachusetts Institute of Technology, LANs = local area networks

[a]Projects listed represent th. broad range of innovative applications of technology to probiems central to cognitive, social, and instructional sciences Of education, particularly in the area of K-12 education. This is by no means an exhaustive list

SOURCE: Office of Technology Assessment, 1988.

- defining the strategies of effective human tutors (knowing how to present information, what problems to present next, when to interrupt, when to explain);
- developing representations of real systems which learners can manipulate and explore, to try out hypotheses and "what if?" kinds of thinking. (What if I change this variable? What if it breaks down? What if I want to make another like it?)
- trying out various student-tutor interfaces to determine how easily the student can get at the knowledge contained in the tutor's ideal student model;[50]
- showing various graphic means which can illustrate ways of solving problems; and
- studying how instruction can be adapted to limitations in the student's attention span or ability to absorb information.

An example of an intelligent tutoring system which incorporates at least limited capabilities in all these areas is the Geometry Tutor developed at Carnegie-Mellon University. ONR funding for early research, later supplemented by NSF support for development and the Carnegie Foundation support for testing in the schools, brought this concept from

[50] "The interface between the user and the computer may be the last frontier in computer design." James D. Foley, "Interfaces for Advanced Computing," *Scientific American*, October 1987. Examples of interfaces are touch-sensitive, plasma-panel screens, the "mouse" pointing device, the chorded key set, and on-screen windows; icons, menus, browsers, overlapping windows, and the bitmapped display; eyetracking; and the Dataglove. (See Brown et al., op. cit., footnote 45, app. III.)

basic research to classroom trials in the Pittsburgh public schools. Other intelligent tutors are being supported by NSF for Pascal programming and an intelligent tutor for high school algebra.

Intelligence Extenders

There is a major class of tools for learning and problem solving, variously described as "cognitive technologies," "intelligence extenders," "cognitive workbenches" or "mental prostheses." These software tools enhance the utility of computers by their capacity to quickly and accurately manipulate symbols, including pictures, text, diagrams, numbers, and sound. They can be used in various combinations as needed.

For example, text editors and graphics tools in word processors enable the writer to manipulate language with new ease and grace. Using these tools, writers find that revisions come more easily, thoughts can be reformatted, rearranged, and given new expressive shapes previously not possible in the world of erasures and cut-and-paste editing. These adjustments and revisions in writing are techniques that are associated with expert performance among writers, yet even the most inexperienced of students can benefit from the assistance these intelligence extenders provide to help them write more fluently.

As these tools now approach second-generation or integrated tool levels, they can be customized by teachers and publishers for different curricular areas and topics. Like dBase III, a powerful general tool for various database applications, or *Lotus 1-2-3,* which offers multiple spreadsheets and modeling applications for business, comparably powerful "engines" for education could spawn customized development and applications by the teacher for classroom use. *HyperCard,* the latest associative tool, allows the

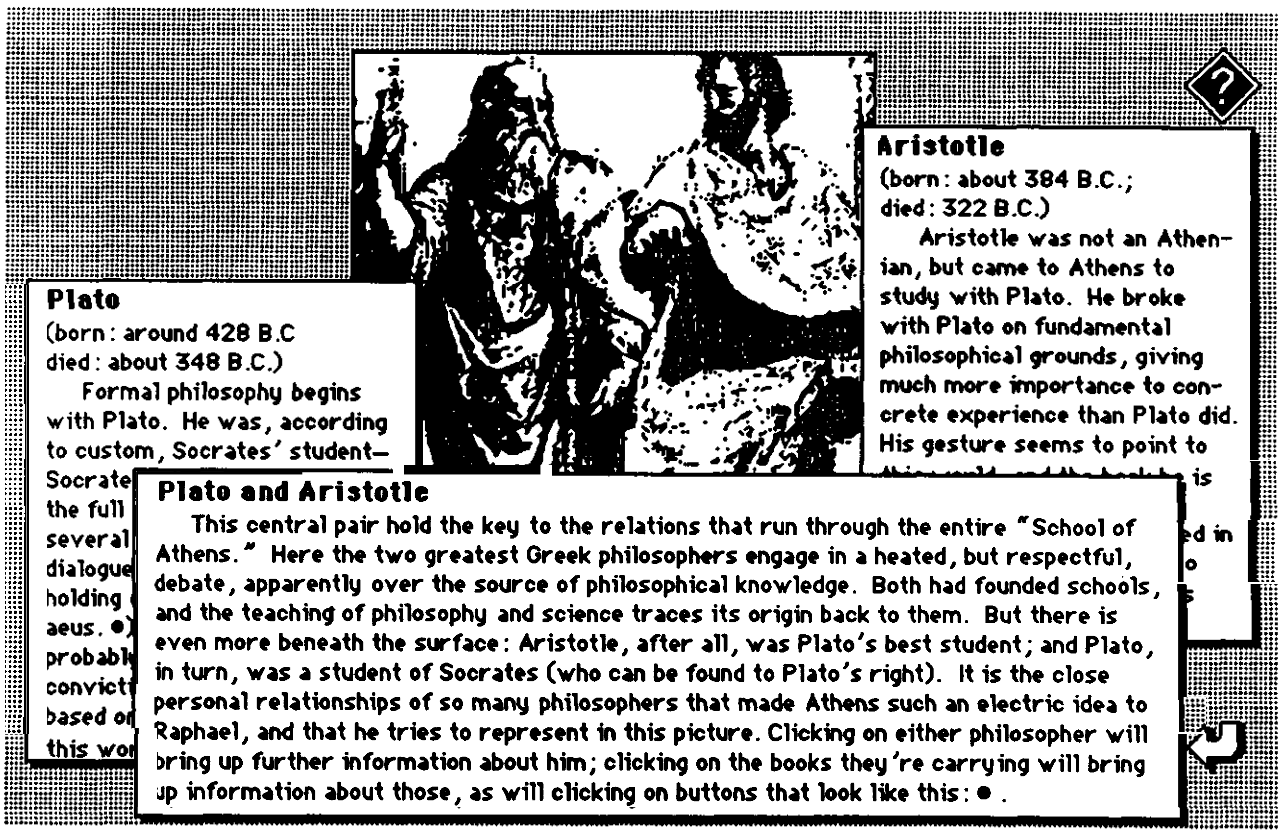


Photo credit: ***John Camp, Wayne State University***

HyperCard software lets teachers create their own instructional software, linking topics as desired. In this "School of Athens" *HyperCard* stack, students "click" on a figure to bring up more information about the philosopher or on the question mark for general information or help.

user to create and link together "cards" of intermixed text, graphics, videodisc images, and sound. This software tool also includes a powerful, but simple, programming language. *HyperCard's* lineage **can be** traced back to Memex,[51] the forerunner of today's "hypertext," "idea processing, " and outline processing systems. Much of the work creating tool **"en**gines" has been taking place at the university level **over** the past 5 years, **as** in Project Andrew at Carnegie-Mellon University, Project Athena at the Massachusetts Institute of Technology, and Brown University's IRIS Project.

Among the **most** promising **uses** of technology tools are those for exceptional students. Innovative projects include braille word processors for the blind, specially designed materials for teaching English syntactic structure to improve the reading and writing skills of the deaf, and synthesized speech generated by touching graphics tablets, enabling students with little **or no** capacity for **oral** language to communicate.

Increasingly Complex Microworlds

In increasingly complex microworlds a computer representation of a situation **or** environment **ena**bles the student to learn about the content area by exploring the representation, and to practice a skill in progressively more complex computer-generated simulated environments.

Microworlds are valuable learning tools because students **can** learn by doing, by acting **on** the microworld rather than merely observing phenomena. They **can** be very powerful stimuli for understanding how things work. Some microworld systems let students build or program their **own** worlds, allowing them to explore the properties of the system and their relationships by examining the consequences of changes to these properties.

For example, in the LegoLOGO project, students write LOGO programs to control Lego machines, connecting programming and real-world objects such as gears, levers, and sensors, to introduce key concepts in physics, engineering, and robotics through an experimental approach. In microcomputer-based laboratories students learn science by doing it. Alternatively, imaginary microworlds **can also be con**structed (e.g., non-Newtonian universes) which offer **new** opportunities to bring to life things that students could never see **or** imagine without the technologies. The microworld **can offer novel op**portunities going beyond the limits of the **real** world, allowing the learner to delve into created worlds of fantasy and exploration. Examples of microworld R&D include systems for early physics learning (Dynaturtle; Thinker Tools); systems for exploring electrical circuit behavior (SOPHIE; QUEST); economic systems (Smithtown); physical systems (STEAMER); and ecosystems (The Vivarium Project).

Multimedia Learning Environments

Print remains the medium of instruction in schools today, just as it was a century ago. Video, audio, graphics and other representation of information are used far less, despite the fact that they **are** highly motivating and effective for learning, and most often the sources of the learning that takes place outside the schoolroom.

Researchers **are** studying ways learners process information presented in nontext media, and how various symbols (pictures, diagrams, graphs, flowcharts, etc.) affect understanding.[52] As discussed in

W M Mo

Photo credit: Adaptive Communications Systems, Inc.

One of the most promising areas of research is technology to serve exceptional students. Typing his words into this computer generates a speaking voice for this young man.

[52]See Mary Alice White, *What Curriculum for the Information Age* (Hillsdale, NJ: Lawrence Erlbaum Associates, 1987).

chapter 8, new developments make it possible to combine video, audio, and graphics to provide information in varying formats that the teacher can control and access quickly. Object-oriented graphics editors, digital scanners for photos and video frames, and animation tools are available for computers at reasonably low cost, and are being used in learning technology development work in the research laboratory.

A future scenario illustrates how these multimedia tools could be used in the classroom. Picture the elementary school teacher discussing earth science and plate tectonics with the class. Using the computer as a multimedia control device, the teacher pulls up for computer projection dramatic online video clips of volcanoes. Students use an interactive microworld to examine how continental drift operates, and slides of fossil remains from different continents show how now-dispersed land masses were once connected. One student has the idea of photographing local geological strata, another brings in a home video of television footage on volcanoes he thinks might be relevant, another tapes the sound of storms to produce an audio soundtrack. When they return the next day these auditory and visual images are scanned into the classroom archives for other students to use. Electronic messages flow between students and from teachers to students when difficulties arise or to share new ways of thinking about what is being learned. Students work at multimedia composition work stations, revealing what they have learned by constructing and revising their own reports about plate tectonics from these and other materials they have found and pulled together.

New Measures of Assessing Learning

Tests play a role in the learning process by telling students what in the curriculum is important.

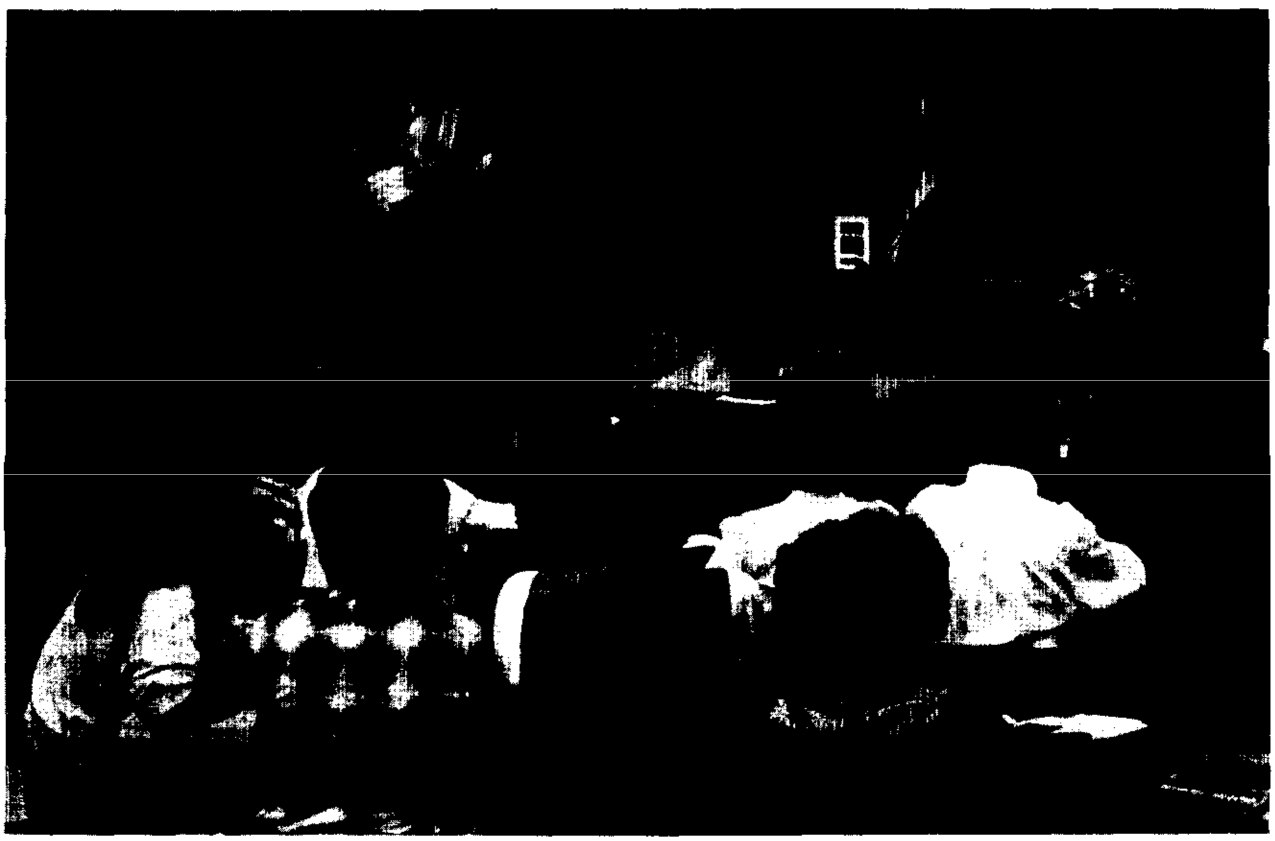


Photo credit: Optical Data Corp.

New developments with interactive multimedia make it possible to combine video, audio, and graphics to provide information in varying formats the teacher can control and access quickly.

If, for example, testing is confined to memorizable end results, teachers will teach facts and students will memorize them to score well on tests, ignoring the more sophisticated levels of understanding and reasoning which education aims to foster. At present, very little school testing is directed toward measuring students' conceptual understanding. Researchers suggest the need to devise new assessment strategies that analyze the attainment of nontrivial skills, with particular attention to "complex thinking skills" such as the ability to generalize appropriately, to invent analogies and use them critically, to take problems apart into interacting parts, to effectively manage and deal with complexity, to lay out a procedure as a sequence of approximations which converge to a solution, and to analyze a situation from a viewpoint other than one's own.

Photo credit: *Kalamazoo Area Mathematics Center*

New kinds of problem solving are made possible using the real-life tools of mathematics, a graphing calculator and computer.

Another important feature of testing should be the ability to diagnose the student's present level of conceptual understanding, taking into account the preconceptions or misconceptions he or she brings to the learning situation. These prior beliefs may frustrate traditional instruction and need to be identified so that the teacher can address them appropriately. Research is needed to develop instruments for measuring deep conceptual understanding and diagnosing prior understandings.

An additional approach to assessment calls upon learners to evaluate themselves as they are learning (e.g., testing comprehension in reading) and to work strategically to overcome difficulties as they are experienced. Here, too, today's tests are inadequate for self-assessment of understanding or skills.

Research on How Technology Affects Teaching and the Social Structure of Schooling

A last but important area of educational research focuses on the social context in which learning takes place. For example, teachers can make a difference by creating and maintaining an open environment in which making mistakes is an accepted part of the learning process, and in which different approaches to problems are welcomed as opportunities for group learning. Such an environment appears to influence whether a student treats work on a problem as an opportunity for learning or as an occasion for failure and low self-image. And a teacher's negative expectations for a student's performance often become self-fulfilling. The computer, with its immediate and private response to the student's input, can be one antidote.

Social relations with peers in the classroom can also be harnessed to contribute to cognitive growth. Numerous studies indicate that group discussions of strategies for solving a problem can be important vehicles for learning, by making explicit to each member the merits of different approaches and viewpoints.

All the ways technology can enhance what students learn, how learning is measured and how the

curriculum can be reconfigured will have major implications for the teacher's role (see chapter 5). Without new training efforts to teach with, not about, technology, the innovations discussed above will make little impact on education. As one researcher said:

> The problem with education now is not what students are capable of, but what teachers are capable of, given their previous education. The main problem of educational research and development is to educate teachers to teach to students' conceptual understanding, and to teach them to diagnose students' alternative frameworks for thinking about what is being taught.[53]

Few experts see the technology replacing the teacher. Some believe that this is what intelligent tutors are being designed to do, but most think only a small part of formal education can be mechanized in that fashion. instead, most experts see ways in which the computer can be used to revitalize the teaching profession. For example, the computer could provide better ways for teachers to see incremental changes in students' understanding of concepts to diagnose areas of special difficulty. This will improve teachers' abilities to teach based on an understanding of the student's particular stumbling blocks.

Computers could also help make the teacher's role more one of "coach" than delivery agent of learning. Such tools as microworlds, word processors, and database programs enable students to work individually or in small groups focusing on problem solving activities. In this mode, peer learning is facilitated, while the teacher guides the students in a process of discovery learning. (See box 7-D.) Some see this as an even more intellectually challenging role for teachers than that required in the lecturer/test-deliverer teaching model common today. Computers could also promote more effective learning for the teachers themselves as they use technology in preservice, inservice, and networking activities.

Technologies may have a special role to play in research on the "Microsystems" of schooling, which deal with the social organization of instruction and curriculum content. For example, networking technologies could fundamentally change the communication systems of classrooms, connecting teachers and students to a nearly limitless number of learning and teaching resources, including information databases and teachers, specialists, and others students, as close as the next seat and as far as across the ocean.

[51] Susan Carey, "Cognitive Science and Science Education," *American* Psychologist, vol. 41, 1986, pp. 1123-1130.

BARRIERS TO IMPLEMENTATION

A number of barriers stand in the way of moving from research to application in the classroom. Many educators fear that without major restructuring of schools, such as allowing teachers much more flexibility in controlling the curriculum, opening up the time-in-grade system to that of student movement based on individual progress in meeting instructional goals, and other improvements to the educational system, no significant changes will or can be made, with or without technology R&D.[54]

Problems of funding, leadership, and strategic planning have been highlighted in previous sections of this chapter, while others are discussed in detail in other sections of this report (see chapter 5 on the teacher's role and chapter 6 on software). There are additional barriers:

- The lack of consistent stable funding means that ideas rarely can be sustained through experimental and applied development with appropriate classroom testing and evaluation. Prototype development is not enough to bring the results of basic research into classrooms.
- The hardware necessary to conduct sophisticated artificial intelligence research is extremely expensive. Small grants or contracts to researchers will not suffice.
- The installed base of technologies in the schools today is not powerful enough to run some of

“’Technology can never replace teachers. But the lack of new technologies in our schools—or the use of technology as if it were no more than a modern blackboard or drill sheet—is certainly squelching real teaching and learning. We've always talked about getting out of the rut of teaching as information dispensing and overcoming a 'one best system' of student learning that denies individual differences and needs, despite all our rhetoric to the contrary. Well, in technology we have the opportunity. The question is, will we take it and what will we do with it?" Al Shanker, president, American Federation of Teachers, personal communication, Mar. 22, 1988.

the more sophisticated software applications produced by advanced research. In order to experiment with advanced applications, research projects need to be allied with schools and make the necessary advanced hardware systems available to them.[55]

- There is need for long-term comprehensive evaluations of different approaches, including those utilizing technology. Schools are justifiably cautious about using real students as "guinea pigs" for radical approaches without some track record of success.
- There is a shortage of research scientists to do this kind of interdisciplinary research. Currently we have not infused ". . . enough sense of national emergency into the work to attract them away from other attractive projects. "[56]
- Differing design features in the technology bedevil the education R&D community and practitioners. Many argue for standards in interface design so research can translate across machines, to ensure compatibility, to reduce learning time for users, and to make finding and storing data easy for even the youngest students.

[55]For example, in order to *test* the *Geometry **Tutor*** in schools, the researchers at Carnegie-Mellon University had to loan computers to the test sites in the Pittsburgh schools. The Geometry Tutor's high-level software required more powerful machines than the schools had. Although the final version has been adapted to run on a Macintosh, even these are rare in high schools at this time.

'George Miller, Princeton University, personal communication, December 1987.

POLICY OPTIONS

The Federal Government has a clear responsibility in supporting R&D for educational technology. Only **the Federal Government can marshal the resources to conduct the R&D necessary for the development of high quality teaching tools and materials, for creating and testing technological systems, and for demonstrating and evaluating the applications of technology to a wide range of educational problems.** Several options are possible.

Option 1: Take No Action

Under this option, current levels of funding and organizations for educational technology R&D in Federal agencies would be maintained. Some suggest that the existing Federal organization for R&D is appropriate and has served to support important research that eventually makes an impact on classroom teaching and learning. Under this option, funding for technology would probably reflect Federal budget restrictions. The private sector could be encouraged to provide greater support for educational technology R&D.

This approach would be appropriate if we wish to maintain the status quo. Some educators feel that technology is overrated and costly. They contend that educational priorities must first address measures that upgrade the teaching profession and restructure the organization of schooling. However, these reforms are also very costly and carry no guarantee of improved student learning. The promise offered by new technologies for improving learning suggest that, although technology has significant costs, it could be as promising an investment opportunity as any other major school reform proposals.

Furthermore, maintaining the current level of effort for Federal R&D on technology could result in missed opportunities for significant educational change. Existing problems in Federal support for R&D (gaps in subject areas, poor coordination, inability to support major, long-term research projects, shortages of research facilities and manpower, and lack of classroom testing and evaluation of products and procedures) would be perpetuated. Finally, adopting a policy of no change would send a signal to the education and research communities that technology is not a priority area for educational improvement.

Option 2: Increase Resources in Existing Programs

Congress could direct Federal agencies to provide a greater focus on educational technology R&D and increase funds for the R&D budgets of existing technology programs. As shown in tables 7-3 and 7-4 and in appendix C, there are many programs that could do more if resources were increased and congressional intent were made clear. Congress could direct the Department of Education and NSF to increase funding for R&D in these programs, while also increasing funding for the 6.1 research components in DoD which contribute to this effort.

Under this approach, agencies could plan to target greater amounts of money over the next 5 to 10 years to R&D in technology. Staged growth would allow for support to greater numbers of graduate researchers whose growing expertise could seed further research. Funds could be targeted at several levels: to individual researchers, to existing centers such as NSF and the Department of Education's Technology Center, as well as other laboratories and centers. These grants and contracts could require school system collaboration, and might require contributions from the private sector to leverage Federal dollars.

Larger levels of support could make possible an integrated approach to curriculum development in areas of special need which require stable, long-term support. For example, a recent NSF planning grant for a pilot demonstration on the use of advanced technologies concluded that ". . . in the absence of private sector investment in the computer curriculums necessary . . . the Federal Government should subsidize their development at an estimated cost of $20 million for eight secondary-school science and mathematics courses."[57] This same report suggested that a front--end investment of between $1 million and $3 million per course is necessary to begin such large scale efforts. Similar levels of effort would be required in other areas of the curriculum.

However, increased funding is not likely to resolve other problems of research coordination and long-term implementation.

Option 3: Facilitate R&D Transfer and Applications

Congress could direct the Federal agencies to adopt policies which would enhance R&D transfer within and across agencies, and from laboratories into schools. Activities could include:

Interagency funding of projects. This is one mechanism that could increase coordination and support larger efforts.[58] However, past experience with this approach points to difficulties of securing interagency agreements on objectives, procedures for awards, and requirements for reports or contracted products. Congress has sometimes viewed joint funding as duplicative.

Collaboration among programs. Support from a variety of discretionary or operating funds within agencies can bring together Federal program managers, in-house researchers, and external grant and contract recipients to present findings on work in progress. Meetings on topics of mutual interest could provide cross-fertilization of research ideas. With better awareness of work in progress, Federal officials could target discretionary and operating funds to developments that seem most promising, as well as to areas where gaps exist.

Coordinating activities and meetings of this scale requires resources—staff time and funds for travel and per diem. While these are not large expenditures, many grants today, especially in the Department of Education, do not include travel funds for researchers, nor have agency staff been encouraged to travel to professional meetings.

Electronic networks for research and dissemination. The history of ARPANET and the recent establishment of research networks in NSF demonstrate the important resource these provide for communication and collaboration among funders, researchers, school practitioners, and policy makers.

[57] Arthur S. Melmed and Robert A. Burnham, "New Information Technology Directions for American Education, " Report for the National Science Foundation, December 1987.

[58] The Departments of Education, Labor, and Defense have supported an innovative technology, transfer program involving the military's Job Skills Education Program (J SEP). Representatives from each agency met for nearly 2 years as an Interagency Working Group on Adult Literacy to accomplish this transfer. With joint funding from the Department of Labor ($500,000) and the Department of Education ($128,000), the military's computer-based job skills educational materials are being converted for use in functional literacy programs in the civilian sector (students in high school and adults in other programs). Florida State University and Ford Aerospace Corp. will transfer the JSEP materials for use on IBM compatible hardware and develop manuals for using the system. Staff from the Army Research Institute who had worked directly on the JSEP program coordinated the details of making this technology' transfer feasible. The Department of Labor is funding three demonstration sites in California, Delaware, and Indiana, where State vocational education and Job Training Partnership Act personnel are playing a kc}' role. New York State is supporting two demonstration sites as well. Karl Haigler, director, Adult Literacy Initiative, L'. S, Department of Education, personal communication, June 1988.

87-002 0 - 88 - 5 : QL 3

Nevertheless, various research communities have limited access to one another, with the education community the most infrequent user. Congress may want to study how national networks can better serve the needs of the education and research community, especially as rising costs discourage network usage.

Congressional oversight. Congress could request an annual or biannual report that: a) reviews the activities of all Federal agencies involved in educational technology, b) identifies opportunities to transfer technology from one type of activity to another, and c) recommends steps to be taken for further research or in transfer activities. Requests for periodic reports to Congress are not unprecedented, particularly in areas of rapid development and high national interest. Periodic reports could motivate agencies to collect and analyze information in a more systematic fashion.

Agencies may consider this an extra reporting burden. Some agencies are organizing information on technology funding and project scope for their own purposes (e.g., DoD), but considerable resources are required to make information databases useful. Assembling an annual report would require expenditures to provide trained personnel to coordinate the assessment and the computer support for developing and maintaining databases.

Option 4: New Initiatives

The magnitude of the problems facing education, increasing demands for a better trained populace to meet international economic competition, and promising applications of technology for learning argue for a different approach. More than band-aids on the existing system may be required; instead, some suggest consideration of totally new initiatives that would provide a national focus on technology and educational improvement. That technology can improve the productivity of the workplace is no longer in doubt. Whether it can offer comparable improvements to education needs to be tested. Major commitments to R&D could explore classroom applications and changes to make learning more productive: allowing teachers time to spend with individual students, coaching and tutoring them; and tailoring instruction to each student's level of understanding, learning speed, and learning style. To find out whether these goals could be realized requires a major investment in R&D. Perhaps it is time for education to invest the same fraction of gross expenditures on research as does the average privately owned business in the United States. If that were the case, about $9 billion a year would be spent for education research. This is 60 to 90 times more than the present allocation.[59]

Options incorporating this level of focus and investment include support for centers for interactive technology and education, major long-term demonstrations of technology in schools, and funding a national "education futures" project, or a combination of the above.

Centers for interactive technology and education. These centers would conduct research, development, demonstration, evaluation, and dissemination of educational technology projects.[60] They would be tied closely to schools and involve teachers in research. The work could be modeled on the Department of Education's Educational Technology Center; the differences would be the scale of effort and funding, the interdisciplinary research focus, and the long-term commitment. Such centers would have several attractive characteristics. They would encourage the coordination of technology use in teaching and learning. They would integrate all stages of R&D, from science to classroom, in one setting, providing opportunities for technology transfer among the center and schools, Federal laboratories, private industry researchers, and university research. They would stabilize the R&D effort, making it possible to attract and keep the best personnel who could see projects through to final evaluation and dissemination. There would be economies of scale, making it possible to support costly advanced hardware and bring together a variety of people from various specialities, enriching the research mix. Finally, centers would provide training opportunities for teachers and graduate students, enlarging and enriching the manpower pool for educational technology R&D.

But there are drawbacks. Such centers are expensive. A new major funding commitment (from $5 to $10 million per year) in a time of budget deficits

[59] See Office of Technology Assessment, op. cit., footnote 1, p. 49.

[60] For a fuller discussion and description of centers for interactive technology and education, see Pea and Soloway, op. cit., footnote 44.

may be unrealistic. Centers could duplicate current efforts. What would be their relationship with existing Federal centers and their research in this area? Would important work in progress now lose support to continue? Would independent researchers still be supported for smaller efforts not tied to the work of the centers? Would new centers strip existing university research centers of their best people, given the shortage of highly skilled personnel? Finally, the long lead time for research applications to reach fruition could be politically unpopular and jeopardize future funding. Experts estimate that many products in the R&D pipeline now could take a decade or more before they can be expected to make a significant impact on the classroom.

Long-term demonstrations of technology. The scale and scope of these demonstration schools would be much larger than current demonstrations that typically focus on one technology product or process with just one class or a small group of students in a school. Technology demonstration schools could be representative of the student population nationwide and involve all the school resources (teachers, researchers, equipment, curriculum, parents, community support) for applying technology in school activities. Demonstration sites would make it possible to evaluate the educational effects of a technology-rich school environment.

The costs of setting up and sustaining demonstration schools would be large, requiring the Federal Government to reimburse States and local districts for the extra required resources. States and districts sponsoring demonstration sites would have to agree to relax standard requirements for curriculum, teacher staffing and salaries, and organizational and administrative restraints, in order to provide a site allowing for experimentation. And not all schools would benefit equally at first, raising concerns about equity and the choice of sites.

A "national education futures initiative" for research, development, and demonstration in educational technology.[61] This option, on the order of $1 billion per year for 10 years, could include the initiatives suggested above, as well as support all levels of research, development, and demonstration; teacher training; software development; longitudinal and comparative evaluations; and dissemination. Congress could include a sunset provision, using the year 2000 as an endpoint, a period in which the Federal effort would make enough of an impact on education to create significant change. In addition to focusing the Nation's attention on technological solutions, an initiative of this order could also strengthen the hardware, software, and telecommunications industries, which have become important industries for U.S. economic competitiveness. Many educators have suggested that the magnitude of U.S. educational problems, and the Nation's decreased economic competitiveness, require an initiative on this order.

This effort would require the establishment of a coordinating body—possibly a new institution made up of staff from existing Federal agencies, university laboratories, school personnel, and members of the private sector.[62] It would draw resources, both personnel and financial, from other sectors as well as from other approaches to educational improvement. Other social programs might suffer funding cuts to support an educational buildup of this order. Finally, this level of Federal activity in education could prove politically difficult if it led to the development of national curricula or national educational standards, or if the public became impatient and did not detect significant educational improvements after the first few years of funding.

Option 5: Support International Cooperation

The European community, Canada, Australia, Japan, Israel, the Soviet Union, and other nations are embarking on major efforts to use interactive technologies to improve instruction. These efforts share common concerns, experiences, and outcomes with U.S. educational technology activities, despite vary-

[61] Models for this level of effort include the Manhattan Project in atomic energy and the Apollo Mission to put a man on the moon. Both these programs sprang from a sense of national emergency and concentrated human, financial, and technological resources in a clearly articulated strategic plan of action. A national education futures initiative would not have the simply defined technical goal that characterized Manhattan and Apollo, but would focus national resources and provide momentum and commitment.

[62] In hearings on Federal educational research, the British "quango" was suggested as a model for a public/private coordinating agency. See Major R. Owens, chairman, Subcommittee on Select Education, House Committee on Education and Labor, "Opening Statement," Oversight Hearings on the Office of Educational Research and Improvement, Apr. 20, 1988.

ing educational goals and cultural differences. There is much we can learn from one another.

As information technologies are used to link students and classrooms all over the world, it may be appropriate to support larger efforts for international cooperation. Congress may wish to consider international cooperative efforts such as sponsorship of conferences,[63] exchange of researchers, and joint funding of projects. Models for this occur in other areas of science, but little has been done to date for cooperative educational technology projects. As the Chairman of the 1987 Organisation for Economic Development and Cooperation conference stated:

> Some educators would advise caution and warn against the possibility of creating too great expectations. . . . Such views are praiseworthy but we should not be daunted by the magnitude of the task. The application of information technology to education requires new and imaginative approaches. The potential return is very high indeed.[64]

On the other hand, some would argue that the resources available for enhancing educational technology in this country are already scarce. To attempt to support international efforts might put too great a strain on our system. Others suggest that the centralized educational systems of other industrial nations, or the special problems of developing nations, would make it hard to generalize research results into useful programs for this country. More study is needed to identify the U.S. position with regard to other countries and to consider ways in which international efforts could proceed.

Conclusions

OTA concludes that increased coordinated support for R&D in educational technology is necessary. Significant improvements in education can be made if sustained support is made available for development of new tools for teaching and learning. The private sector, while a contributor to this effort, does not have the primary responsibility or appropriate vision for making this a priority. States and localities do not have the capacity. The magnitude of the challenge facing education, allied with the potential offered by new interactive learning technologies, requires that the Federal Government accept this responsibility and opportunity for leadership.

[63] The Center for Educational Research and Innovation of the Organisation for Economic Cooperation and Development has sponsored international conferences on education and information technology. See Organisation for Economic Cooperation and Development, *New Information Technologies: A Challenge for Education* (Paris, France: 1986); and Organisation for Economic Cooperation and Development, *Information Technologies and Basic Learning (Paris, France:* 1987).

[64] Quote from Denis Healy of Ireland, *Information Technologies and Basic Learning,* sponsored by the Center for Educational Research and Innovation (Paris, France: Organisation for Economic Cooperation and Development, 1987), p. 13.