Chapter 8

Technology and the Future of Classroom Instruction

Photo credit: Education Week

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Technology and the Future of Classroom Instruction

. . . the computer is an innovation of more than ordinary magnitude, a one-in-several-centuries innovation and not a one-in-a-century innovation or a one-in-ten years innovation or one of those instant revolutions that are announced every day in the papers or on television. . . .
Herbert A. Simon[1]

What we need to do, then, is to educate as though this technological revolution is what it really is—the third learning revolution—the most important change in learning since the 16th century.
Mary Alice White[2]

INTRODUCTION

The current wave of educational technology, which began roughly in 1981, when schools first began acquiring computers in large numbers, is a good news, bad news, good news story. **The good news is that schools showed a remarkable willingness to invite computer technologies into the classroom, and to see how these interactive cognitive tools could be applied in a setting devoted in large part to training young minds to think.** American schools are often criticized for their slowness to change,; for their lag in adapting to modern times. Yet their eager embrace of computer technology may signify a break with the past: despite the constraints of local budgets and the exigencies of distributional equity,[4] the United States has been among the world's leaders in providing public school children access to new technologies. The fact that U.S. schools were willing to meet the challenge of the new information world and to attempt to integrate a nascent tool into their already dense curricula is perhaps more important than the limited "proof' of educational improvements.

The bad news, however, must be reported too: even this remarkable achievement in the schools pales in comparison with the rate and magnitude of entry into the age of information experienced by business, the military, higher education, and medicine. A handful of classrooms have one computer for each child and another one for the child to use at home (see box 8-A). But in general, classrooms today resemble their ancestors of 50 and 100 years ago much more closely than do today's assembly plants, scientific laboratories, and operating rooms. A number of information technologists point out that if business organizations today evolved at the same rate as the schools, they would still be using quill pens instead of electronic word processors. It might be argued that the complex goals of education are not necessarily advanced by application of new electronic gadgets, and certainly not in the same obvious way that accounting tasks have been simplified with the electronic spreadsheet or file management has been streamlined with database systems. Nevertheless, the chasm in technological sophistication between our schools and the environment in which students will work gives pause.

But there is more good news: under the right conditions there is reason to hope that the new technologies will continue to spur major school

[1] Herbert A. Simon, "The Computer Age, " *Computers in Education: Realizing the Potential*, Report of a Research Conference (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement, August 1983), p. 37.

[2] Mary Alice White (ed.), "Information and Imagery Education," *What Curriculum for the Information Age?* (Hillsdale, NJ: Lawrence Erlbaum Associates, 1987), p. 63.

[3] See, for example, David K. Cohen, "Educational Technology and School Organization, " paper prepared for the Conference on Technology in Education in 2020: Thinking About the Not-Distant Future, Harvard University Educational Technology Center, Oct. 15-17, 1986. This conference was supported in part by OTA. This paper and others presented at the conference will be published in Raymond S. Nickerson and Philip P. Zodhiates (eds.), *Technology' in Education in 2000* (Hilldale, NJ: Lawrence Erlbaum Associates, in press).

[4] See James Guthrie, "Campaign '88 and Education: A Primer for Presidential Candidates," *Phi Delta Kappan*, vol. 69, No. 7, March 1988, pp. 514-519.

Box 8-A.—Apple Classroom of Tomorrow

In the Apple Classroom of Tomorrow (ACOT), each student and each teacher has a personal computer at school and another one at home. These computer-saturated classrooms now reach grade 2 and 3 children in Cupertino, an affluent community in California's Silicon Valley; grade 5 and 6 students at an inner city school in Memphis; a grade 4 suburban school class in Nashville; grade 9 and 10 classes in downtown Columbus, Ohio; and grade 5 and 6 students in Blue Earth, a rural Minnesota community.

ACOT attracts much attention, and ACOT schools are regularly visited by television and newspaper reporters, community members, parents, and other educators. Perhaps the positive effects can be attributed to this special attention, but teachers note that the children adapt rapidly, with little difference between their performance in this "fish bowl" environment and a normal one.

ACOT teachers have common experiences, in spite of the many different conditions, personalities, attitudes, and levels of computer expertise. In particular, many teachers report they are exhausted from the increased stress of learning new skills, evaluating software, and inventing ways of incorporating the computer into the curriculum. But they are also renewed by the effect of their travails on students. They have found a new source of pride in and enthusiasm for their profession.

For some students, having a computer at home has elevated their interest in homework; others derive extra esteem from becoming the family computer expert; and many students watch less television. In Memphis, the children have a modem at home and access the ACOT bulletin board. For children who are home bound with family obligations, such as caring for siblings, and for those who are shy and relatively uncommunicative in person, being able to use the computer as an electronic mailbox inspires a surprising flood of communication.

A computer on every desk creates an entirely different educational environment from a room with a few machines at the back of the class or a school laboratory attended only once or twice a week: computer use in these special places averages about 50 percent of the school day. Where the computers are networked, software is centralized and computer activity is more strictly controlled than in classrooms where the computers stand alone and students load their individual collection of software diskettes. There are advantages and disadvantages in each system. A networked system can ensure that students are attending to the same program, and can facilitate recordkeeping and management. Separate computers reduce teacher control over the activity of each student; but students seem to have greater confidence and mastery of the technology and to branch out on their own to explore different software when they have completed an assigned task.

Cupertino ACOT classrooms incorporate computer use into many areas of the curriculum. The teachers often gather the children around only one computer to demonstrate new software or to engage them in group activity. At other times two or three students work together. They also work alone on keyboarding, writing, and mathematics. In Columbus, the ACOT high school classrooms are networked. Teachers design assignments and download them to the students in the class. They manage records easily, and even administer tests on the computer. Unlike other ACOT sites where students use the Apple IIe or IIgs at school and the IIc at home, in Columbus, they use the Macintosh. This has caused some interesting problems and inspired equally interesting solutions. There is relatively little educational software available for the Macintosh, which is primarily a business computer. As a consequence, the mathematics, science, social studies, and English teachers have had to find ways to use business word processors and spreadsheets in content areas. The students have developed expertise with the kind of utility software they are likely to encounter in the job market, while the teachers have learned to tailor the software to individual course and subject needs.

These ACOT classrooms bear little resemblance to conventional classrooms with a few computers. The noise level, with machine fans, printers turning out paper copies of writing assignments, and students asking each other and teachers for assistance, is comparatively high; but concentration, excitement, and engagement are also high. Teachers rarely lecture to the class; more often they move from student to student dealing with individual problems. The students are not magically transformed; they still yawn, poke their neighbors, and daydream, but they appear to do so much less frequently. Both teachers and parents claim that students are more interested in school, more involved, and more confident. The children say that having a computer makes school work more fun, less boring, or a lot easier.

SOURCE: OTA site visits and interviews, 1987.

improvements. Polled for their interest in emerging technologies, over 20 percent of public school teachers were found to be "very interested" in networks, integrated learning systems, on-line database access, and distance learning. Perhaps even more impressive, 31 percent of surveyed teachers indicated that they ". . . would like to see publishers concentrate on developing innovative *programs that teach problem solving and higher order thinking skills,"* while 17 percent desire software that". . . reinforces and closely matches the skills taught in the basal textbook series."[5]

[5]TALMIS, "The K-12 Market for Technology and Electronic Media: A Research Report Prepared for TALMIS Continuous Information Service Clients, " unpublished manuscript, March 1988 (italics added).

If this level of enthusiasm can be sustained, new information technology may prove to be a principal catalyst of educational improvement. Some of the economic and institutional prerequisites have been the subject of preceding chapters. This chapter takes a close look at the technology itself, and asks: What can state-of-the-art information tools do for classroom learning?

CONVERGENCE OF INFORMATION TECHNOLOGIES

As indicated earlier (see chapter 2) the desktop computer is currently the prevalent electronic tool used for instruction in U.S. elementary and secondary schools. However, along with acquisition of computers, schools are gradually becoming consumers of communications and mass storage (memory) technologies. The former refer to technologies that connect students or teachers working in different places via phone lines or other electronic link; the latter are devices that store large quantities of data, such as magnetic disc or optical media. Many of the new learning tools are computer related: they must be connected to a computer to be functional. Others can be used independently, but their appeal stems largely from a principle of "interactivity" made familiar by computers. In video, for example, which is already found in over 90 percent of schools, the advantage of the videocassette recorder (VCR) over ordinary television is "time shifting. " Few teachers today would settle for less than the ability to control the timing, if not the selection of televised programs.

It is the convergence of information technologies that holds the greatest potential for the development of new learning and teaching tools. In some instances, the three principal information technologies—computer processing, telecommunications, and television (video)–have already converged into state-of-the-art instructional applications. A good example is the marriage of video and computer technologies through digital video interactive (DVI), developed by researchers at the David Sarnoff Laboratory. The Center for Children and Technology at the Bank Street College of Education has applied DVI to a project called PALENQUE, which affords users a television "walking tour" of that ancient Mayan village, as well as the occasion to control the direction and order of their tour (see photo). Perhaps most exciting about PALENQUE is that users can collect images in a "scrapbook" for future viewing and studying.

There are other examples of convergence. The Kids Network Project uses computing and communications to allow children to collect and process scientific data and transmit their findings to peers across the country.[6] Electronic teleconferencing, made possible by the convergence of television and switched (telephone) communications technologies, is commonplace in large corporations and is gradually finding applications in schools.

Distance Learning

Although instructional television has been widely used for several decades, more recent advances that

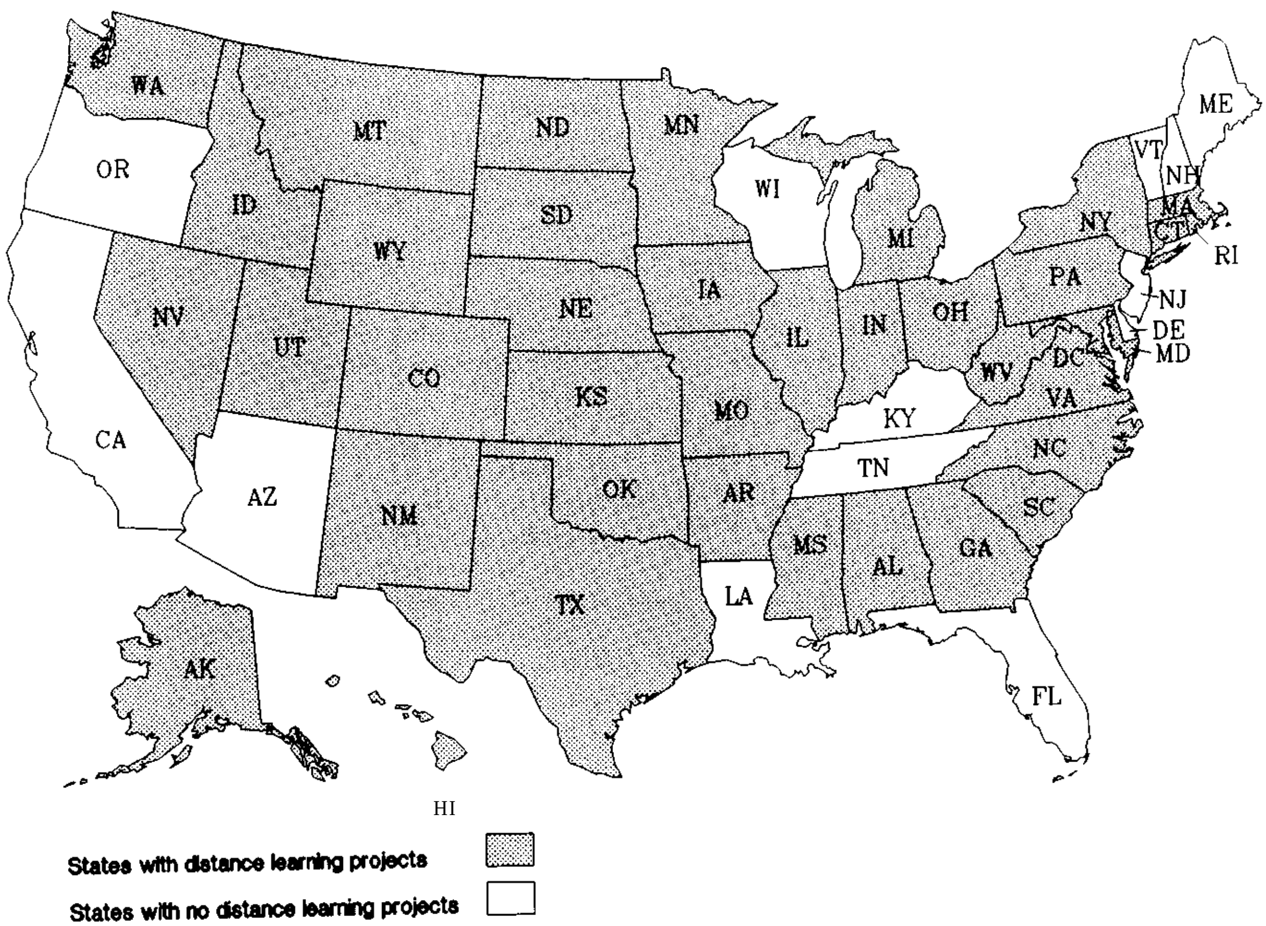
[6] For details, see Technical Education Research Centers, "National Geographic Society Kids Network Project, Annual Report, October 1986 -September 1987," n.d.

enable teachers and students to communicate interactively over thousands of miles have special appeal. There are many rural and isolated communities with teacher shortages where "distance learning" has overcome potentially significant instructional barriers. Distance learning allows students to hear and sometimes see teachers, and, perhaps more important, allows those teachers to react to students' questions and comments. The declining costs and increased accessibility of satellite technologies have enabled 35 States to support some type of distance learning program[7] (see figure 8-l). Transmission methods vary. Some involve two-way video and audio while others make use of electronic mail services for communication and evaluation of homework.

Some State distance learning programs offer courses developed and taught by local educators, while others offer courses provided by universities, private organizations, or other States. In most cases, distance learning courses are similar to regular courses, with teacher lessons, print--based materials, and tests. For example, TI-IN Network, Inc., a Texas-based private company, provides courses and staff development opportunities via satellite to more than 250 subscribing school districts and other educational agencies in Texas and in over 20 other States. During the 1986-87 school year, TI-IN offered 23 high school courses, including calculus, honors English, Latin, and computer science and over 400

[7] *Electronic Learning*, "Educational Technology 1987: A Report on EL's Seventh Annual Survey of the States," vol. 1, No. 2, October 1987, p. 41.

Figure 8-1 .—States With Distance Learning Projects



SOURCE: Electronic Learning, "Educational Technology 1987, A Report on EL's Seventh Annual Survey of the States," No. 2, October 1987 hours of inservice training. Master teachers in each subject broadcast their courses from studios located in San Antonio and at California State University in Chico. Each subscribing school receives the signal via satellite. Students view the lesson and communicate with the teacher via a telephone call-back system. Students who miss a class need not miss a lesson but can watch it later on videotapes

New transmission technologies, such as fiber optic cables, will help facilitate the delivery of video, audio, and computer communications allowing many more signals to travel over one fiber than can travel over many conventional copper cables. As one example, seven rural school districts in Minnesota use a system of fiber optics, multiple video monitors, and cameras to link together classrooms up to 78 miles apart so that the teacher can see students in up to three other locations simultaneously. The originating classroom has eight video monitors and three cameras: one on the teacher, one on the students, and one above the teacher's desk for demonstration materials. Three monitors, a camera, microphone, and telephone are installed in each remote classroom. [Y]

Facsimile transmission (fax) is another technology that has recently become inexpensive enough to be used in distance learning projects. Fax units now cost about $1,000. Students and teachers with access to such machines can send documents over telephone lines: each telephone in a fax link is connected to a device about the size of a VCR, which produces a printed copy of transmitted material. What normally would require photocopying and mailing of a document can be accomplished in minutes.

Networking

Networking is a generic concept that includes different types of communications links, usually computer-related. Local area networks (LANs) connect the computers in a laboratory or school to common data sources, programs, and peripheral devices such as printers. It is estimated that 13 percent of American public schools have some type of networked computer facility for instruction.[10] Typically when LANs are installed they link computers

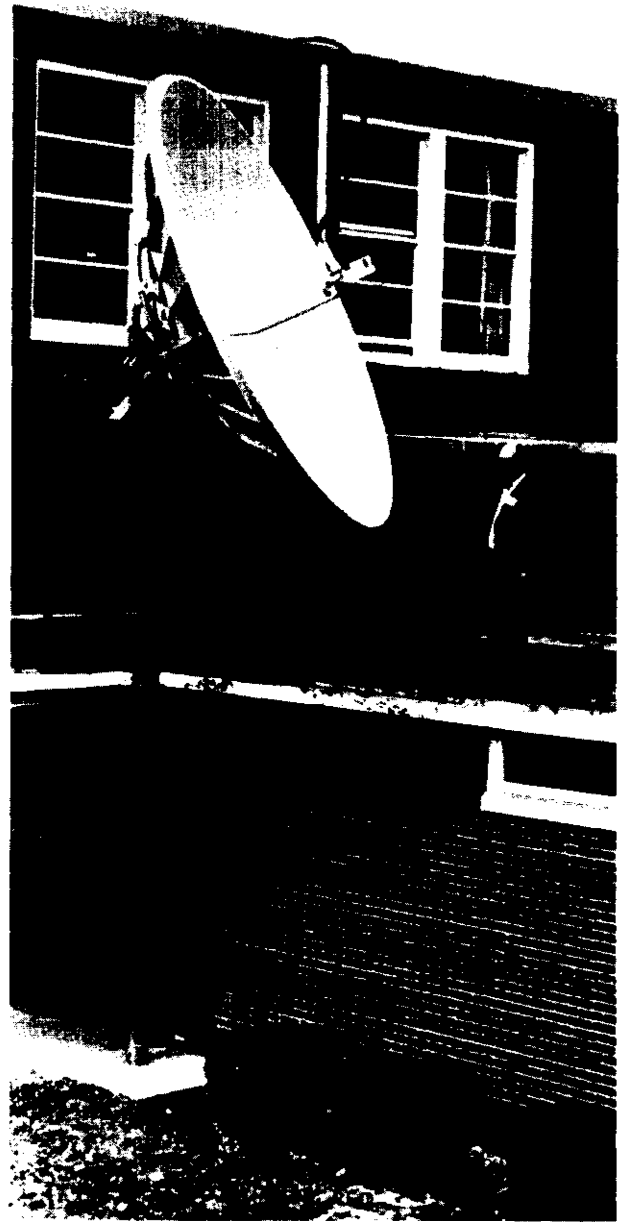


Photo credit: Agency for Instructional Technology

John M. Bedford, of the Strongsville, Ohio school system, stands beside the satellite dish that receives programming directly from public station WVIZ.

‘Gregory M. Benson, Jr. and William Hirschen, "Distance Learning: New Windows for Education, " T. *H.E. Journal*, vol. 15, *No.* 1, August 1987, p. 63.

"Robin Lanier, "Interactive Telesystem Breaks New Ground," *EITV*, June 1986, p. 35. For other examples of distance learning configurations see Karen Kitchen and Will Kitchen, *Two-Way Interactive Television for Distance Learning: A Primer* (Alexandria, VA: National School Boards Association, 1987).

[10]TALMIS, op. cit., footnote 5.

already found in the school, and do not include special software for electronic mail or monitoring of student progress through computerized lessons. However, some experimental projects and recently introduced products incorporate such educational networking software.

Modems are devices that permit the transmission of data over regular telephone lines. They have led to the creation of thousands of informal networks: users sharing ideas, programs, data, and messages. There are currently over 6,000 schools (about 7 percent) with computers connected to modems.[11] Schools, therefore, are slowly beginning to take advantage of the many available on-line financial services, news, database services, and public information networks that businesses and homes have enjoyed for years. Experimental projects have also been designed and implemented that exploit modem communications for nationwide sharing of student research data (see box 8-B).

Some teachers reach their colleagues on-line from home via commercial networks like CompuServ or the Source, or via networks set up by their districts, regional education service centers, or State education agencies. Judging from lists published in the bulletin boards themselves, public access educational boards number at least in the hundreds, perhaps thousands.

In addition, there are a growing number of online services designed expressly for teachers and students working in classrooms or school computer laboratories.[12] One example is MIX, a commercial network for education operated by McGraw-Hill. In December 1987, high school students in different classrooms began participating in an international negotiations game, with each classroom representing an opposing power. Other conferences had students communicating with electronic pen pals across the Nation and in foreign countries; one allowed teachers and their students in agriculture classes to hold a corn growing contest (see table 8-1).

There are few teachers with telephone lines in their classrooms, but many of them are creatively

[11]Quality Education Data, Inc., *Microcomputer Usage in Schools: A QED Update* (Denver, CO: spring 1988).

[12]Earl Dowdy, "Computer Networks in Elementary and Secondary Education," OTA contractor report, October 1987, p. 4.

Box 8-B.—Earth Lab

The goal of the Earth Lab project, developed at the Center for Children and Technology at Bank Street College of Education, was to create an environment for collaboration in the collection and analysis of scientific data in typical school settings. The Center received $785,000 from the National Science Foundation (NSF) for research, development, and testing of the new system, which included database, report writing, and communications software, and curriculum materials on weather, climate, dinosaurs, and plate tectonics. A Harlem public school's sixth grade classrooms became the test site.

The Earth Lab system allowed multiple users to work alone or in groups and send results to their teachers or to other groups in the school, as well as in classrooms in New York, Hawaii, and Boston.

In the first year, researchers developed the prototype, and in the second year they continued development and observed results. Researchers observed a significant increase in student collaboration compared to activities that occurred before the project began:

> Students were able to work together, to think things through, to reason about the problems, and invent their own questions about the data, instead of simply reading from books or being assigned individual worksheets by the teacher.

The network provided a wider audience, and many students wrote more:

> The ease with which they could send letters to other people seems to have motivated writing in science and social studies. Students are now accustomed to using writing as a way to communicate, as opposed to writing for the purpose of giving an assignment to the teacher.

At the end of 2 years, Earth Lab was far from becoming a viable commercial product. Software was often patched together to get it running, and additional research and documentation to support development was needed. However, NSF did not fund continued work. Researchers do not believe that any commercial publisher would put the necessary work into completing and marketing the product: "The number of sales a publisher could anticipate would not justify the investment."

SOURCE: OTA site visits and interviews, 1987.

Table 8-1.—On-Line Conferences for Teachers and Students Available to Subscribers to MIX (McGraw-Hill Information Exchange), December 1987

Conference name	Description
stix. talk	Discussion and information about STIX projects
pen pals	Student pen pal conference
debate	On-line debates for high school students
student, books	Student compiled books dbase; discussion
round robin	Shared student story writing
time. capsule	Student collection of writing on one day
writers assist	Student writers' assistance by students
video	Student video exchanges
logo. pen pals	Student pen pals via LOGO projects
us. ussr	Communications between Minnesotan and Hawaiian students about USSR
Australian .reg	Registration/information on the Australian Bicentennial Project
living, history	Interact with living figures from history
other, side	Global conflict simulation for students
politics	Student interaction with politicians
orillas	Bilingual and foreign language sister classes
coordinacion	For Project Orillas Coordinators
astronomy	Minneapolis Planetarium staff on-line
water	Student water data collection/discussion
flat earth	Students v, Flat Earth Society
twistedscience	Students argue/explain science to Dr. Misconception
science	Science discussion, experts, data from 86-87
zoo	Minnesota Zoo Online
weather	Weather data and experts on-line
plant	Online plant growth data project
weather, data	Weather maps, tables, etc. from the U.S. Weather Service

SOURCE: MIX, McGraw-Hill Information Exchange, December 1987

experimenting with networks. As shown in table 8-2, there are already several exemplary efforts underway in various subject areas that exploit the convergence of processing and communications technologies. Cooperative science and writing projects for students are being developed by some groups; teachers and administrators are collaborating on curriculum research and development and writing with this technology.

The number of commercial and informal networks is expanding as the cost of operating local bulletin boards is dropping. However, important policy questions related to pricing and regulation of telephone communications must be addressed before networking becomes a regular feature of classrooms. In particular, there is the question of whether information transfer companies (such as CompuServ or the Source) should pay access charges to local telephone companies (as do long-distance telephone companies).[13]

Audiographic Communications

A different kind of communications system, called audiographic, allows teachers or students in one location to communicate with others in distant locations via a common electronic graphics system and telephone conference call. In Norwich, New York, 18 rural schools are connected by telephone lines to a central location where a teacher with a regular class has an AT&T Alliance teleconferencing bridge. Each location also has an electronic graphics system, called the Optel Telewriter 1 l-PC, a desktop device that is easily moved from student to student, The students gather around the computer, tablet, and speaker phone. The teacher or any participant can then write on the tablet or type on the keyboard and their input shows up on all of the remote graphics system screens in the network simultaneously.[14]

Broadcast

Broadcast television also has the potential to disseminate computerized information. Experiments to broadcast software to schools have been conducted by the Software Communications Service, an organization of 17 State-licensed public broadcasting systems and 5 Canadian provinces. A demonstration program in Maryland showed broadcast television's capacity to carry computer information, along with pictures and sound. It will eventually be possible to distribute instructional software to thousands of schools at a fraction of the cost of conventional distribution.[15]

An experimental project in Kentucky takes advantage of slack in the State's enormously powerful *Early Warning System* network, a Department of Defense facility that provides advance notice of incoming missiles. A mainframe computer at Western Kentucky University uses telephone lines and the emergency broadcast system to communicate with terminals at the 21 participating schools. One advantage of this communication link is its cost-effectiveness: using long-distance calls to connect to

[13]The Federal Communications Commission recently postponed indefinitely its ruling to charge access fees to information networking companies following a massive "electronic" letter writing campaign mounted by subscribers to popular information network services. Such fees would significantly raise the costs of telephone data communications and could severely hinder schools' abilities to use bulletin boards and other networks.

[14]Benson and Hirschen, op. cit., footnote 8, p. 65.

[15]Brian K. Callahan, director, Learning Technology\, Central Educational Network, personal communication, January 1988.

Table 8-2.-Examples of Electronic Networking Projects in Education

Project	Subject/activities	Participants	Sponsors
Big Sky Telegraph	Teacher training and support	114 one-room rural schools in Montana	Western Montana College; Murdock Charitable Trust; Mountain Bell Foundation; Fund for the improvement of Post Secondary Education
Bread Net	Writing project for English teachers and their students. (Teachers plan lessons via computer conference or electronic mail; students exchange compositions and information electronically y.)	1,023 students, 60 teachers in 45 classrooms in rural schools across the U.S. (2 sites in London and Lima)	Bread Loaf School School of English; Middlebury College; Apple Education Foundation; private foundations
De Orilla a Orilla (from Shore to Shore)	Bilingual education: communication through writing to promote bilingual literacy	20 classrooms in San Diego, New England, Puerto Rico, and Buenas Aires. 5 classrooms from Quebec Province to be added	New England Multi-Functional Resource Center, University of Hartford, and Quebec Ministry of Education
Kids Network	Science activities on weather forecasting, acid rain, water pollution, etc. Students/classrooms collect data, make measurements, analyze results, and share them via the network	Students in grades 4-6 in 200 classrooms, participating in a national field test and evaluation	Technical Education Research Centers/National Geographic Society; National Science Foundation
PSI Network	Technical assistance and information exchange in science education (People Sharing Information Network)	Inter- and intra-state computer conferencing system links State science supervisors and other science education policymakers	National Science Foundation; IBM

SOURCE. Office of Technology Assessment, 1988.

the schools in remote areas would be prohibitively expensive.[16]

Integration of Technology

In the future, many benefits will flow from the implementation of digital integrated networks. These systems, such as the Integrated Systems Digital Network (ISDN), provide digital communications for voice, data, and video signals, and will make computer networks and related services much cheaper.

[16] *Electronic Learning*, "Kentucky's CAI Capability," vol. 5, No. 5, February 1986, p. 10.

It may become possible for any home, office, or school to access any combination of computer programs and video, data, or audio information sources from anywhere in the world. Due to enormous capital costs and long-range planning necessary to install this kind of "information infrastructure, " most telephone companies target full implementation of ISDN for the beginning of the 21st century, at the earliest.[17]

[17] For a discussion of Integrated Systems Digital Network see U.S. Congress, Office of Technology Assessment, *International Competition in Services* (Washington, DC: U.S. Government Printing Office, July 198'7).

ADVANCES IN MEMORY AND DATA STORAGE TECHNOLOGIES

The advent of cheap and efficient microminiaturization in electronics has spawned new digital storage media that dwarf their low-density floppy-disc predecessors (see figure 8-2). Schools lag behind other sectors, including industrial and military training, in the acquisition and implementation of these advanced technologies. Although today's typical classroom computer (such as the Apple 11-e) has much greater capacity than its forebears of 11 years ago (e.g., the Commodore PET), it is still extremely limited in the size of programs it can run (see table 8-3). And although it is possible to link desktop com-

Figure 8-2.—Evolution of Computer Storage Media

Medium	Type	Storage Capacity	Equivalent
Cassette Tape	Magnetic Serial	30 minute tape = approx. 67 Kilobytes	13 pages of text
8 inch Floppy Disc	Magnetic Random Access	416 Kilobytes to 1.25 Megabytes	80 to 250 pages of text
5.25 inch Floppy Disc	Magnetic Random Access	143 Kilobytes to 1 Megabyte	30 to 200 pages of text
3.5 inch Floppy Disc	Magnetic Random Access	100 Kilobytes to 800 Kilobytes	20 to 160 pages of text
Hard Disc	Magnetic Random Access	5 to 40 Megabytes (typically)	2 volumes to 15 volumes
CD-ROM	Laser Optical Random Access	550 Megabytes	Complete Encyclopedia

As new storage media have been developed, the density of information capable of being stored on each successive generation of storage device has increased dramatically. For example, the 5¼-inch floppy disc represents a 150-fold increase in the amount of storage per square inch over cassette tape. The 3½-inch disc has approximately twice the density of the 5¼-inch disc. The storage density of CD-ROM is approximately 1,500 times that of the 5¼-inch disc.

SOURCE Office of Technology Assessment

puters to high capacity storage devices, the latter are still not found in most schools. Nevertheless, the capacity of interactive media to store entire libraries of information and to provide high resolution graphics, full-motion video, sound, and text has attracted a growing community of scholars and educators.

CD-ROM

Compact disc-read only memory (CD-ROM) units can store over 500 megabytes of digitized data and programs. There are already some integrated instructional systems that use CD-ROM to house software.[18] Other examples include the General Post Office in Great Britain, which has placed 23.5 million addresses on one CD-ROM; the 31 volume *Grolier Encyclopedia;* and Standard and Poor's *Compustat PC Plus,* a compilation of traded companies and annual report data. Only a handful of

[18] For one example see ch. 4.

Table 8-3.—Advances in Technical Capabilities of Computers Used in Schools, 1977-87[a]

Computer	Processor	Memory	Display[b]
Commodore Pet Models 2001, 4016, 4032 (1977) discontinued	6502 8 bit	8K	Black and white; 40 characters by 25 lines
Radio Shack TRS-80 (1977) discontinued	Z-80 8 bit	16K	Black and white; 40 characters by 23 lines
Apple II+ (1977) discontinued	6502 8 bit	48K - 64K	Color; 40 characters by 24 lines; 15 color low resolution at 40 by 48; 8 color high resolution at 280 by 192
Texas Instruments TI 99/4A (1979) discontinued	9900 16 bit	16K - 64K	Color; 32 characters by 24 lines; 16 colors at 256 by 192
Atari 400/800 (1979) discontinued	6502 8 bit	16K - 64K	Color; 40 characters by 24 lines; low resolution, 40 by 24, 16 colors; medium resolution, 160 by 96, 8 colors; high resolution, 320 by 192, 2 colors; (total available palate has 128 colors)
Commodore Pet Models 8032, 8096, 9000 (1981) discontinued	6502 8 bit	8K	Black and white; 80 characters by 25 lines
Radio Shack Color Computer (1981)	6809 8 bit	4K - 32K	32 characters by 16 lines; 8 color low resolution at 32 by 16; black and white high resolution at 256 by 192
IBM PC (1981)	8088 16:8 bit	64K - 128K	Black and white; 80 characters by 25 lines; color (optional) 16 foreground and 8 background colors; high resolution, 320 by 192, 4 colors
Commodore 64 (1982)	6510 8 bit	64K	40 characters by 25 lines; 16 colors at 320 by 200
IBM PC Jr. (1983) discontinued	8088 16:8 bit	64K - 128K	80 characters by 24 lines; 4 color high resolution at 640 by 200; 16 color, medium resolution at 320 by 200
Apple IIe (1983)	6502 8 bit	64K - 128K	40 to 80 characters by 24 lines; 7 color high resolution at 280 by 192; 16 color low resolution at 40 by 48
Macintosh (1984)	68000 32:16 bit	128K - 512K	80 characters by 24 lines; black and white screen resolution at 512 by 342
Apple IIGS (1986)	65816 16 bit	256K - 1 Mb	40 to 80 characters by 24 lines; 4 color high resolution at 640 by 200; 16 color medium resolution at 320 by 200
IBM PS2 - Model 25 (1987)	8086 16:8 bit	640K +	80 characters by 24 lines; 256 color high resolution at 720 by 400

[a]These specifications represent the most typical configurations found in the classroom and do not reflect the many variations that are possible with peripheral add-on memory and color cards, for example.
[b]Manufacturer's specifications ar. not always consistent in the description of graphics resolution modes and display capabilities

SOURCE: Office of Technology Assessment, 1988

U.S. public schools, however, currently own CD-ROM units.[19]

Analog, Digital, and Optical Storage Media

Phonograph records, audiotapes, and videotapes have long been used to store pictures and sound, and have become abundant in schools as the costs of consumer electronics have dropped. The videocassette recorder for example, is now found in most schools, and offers several important features: teachers can record and play back selected broadcasts, they can rent or purchase selected tapes, and they can preview programs on their home VCRs. In addition, the VCR is a simple technology to install and use.

Laser optical storage technologies such as the **videodisc** can be used to store both analog and digital information. (For an explanation of the differences between analog and digital, see box 8-C.) The storage density of the laser videodisc is astonishing: on one side of a 12-inch disc, 54,000 individual pictures can be stored along with stereo audio and digital data.[20] In the last 5 years, laser videodisc programs have been developed for military and industrial training, and for advertising and education.

[19]TALMIS, op. cit., footnote 5, reports between 2 and 5 percent of schools with CD-ROM, depending on grade level.

[20]Ben Davis, "Image Learning: Higher Education and Interactive Video Disc," *Teachers College Record, vol. 89,* No. 3, spring 1988.

Box 8-C.--Analog v. Digital

The difference between analog and digital technology is perhaps easiest to understand through a simplified description of phonograph records and compact discs (CDs). With phonograph records, sound is picked up by a microphone that transforms sound waves into electronic waves. The electronic waves are impressed on the record in the form of fluctuations in the amplitude of the groove. When the record is played, these vibrations are sensed by a stylus (or needle) that sets up similar vibrations in the amplifier and then in the cone of a loudspeaker. The loudspeaker pushes the air and transfers the same vibrations to the ear.

With digital CD technology, the sound is taken from the microphone into a processor, broken up into miniscule entities of time, and analyzed and converted into on/off pulses. In computer terms, these on/off pulses are ones and zeros that are encoded onto the CD. This is called analog-to-digital conversion. When a laser beam scans the tracks of the CD it sends these ones and zeros to another processor which interprets them as discrete increments of sound and creates a new wave form out of them. This is called digital to analog conversion, and the resulting signal drives the speaker to reproduce the sound.

The trouble with analog signals is that they lose their strength and acquire noise as they pass through a medium (such as wire), just as sound does as it travels through the air. Moreover, each time a signal is copied it also loses fidelity. The advantage of digital technology is that after signals have been converted to on/off pulses, even though the strength of the signal may deteriorate, as long as the receiver of the information can distinguish on from off, it can reproduce the original information exactly. Therefore, no loss of fidelity will occur when digital messages are transmitted or copied. This means that each copy will be equal to the original and transmissions of information can be made with little or no degradation,

Photo credit: Optical Data Corp.

Computer-generated interactive videodiscs offer new ways to present information combining video, audio, text, and graphics, They use a computer to control the playback of audio and video from the videodisc player, sometimes adding computer-generated text and graphic materials, so that sequences can be arranged to suit the input of the viewer/participant. Schools seem to be increasingly aware of videodisc technology, but it is unclear how many own and/or use videodisc players.[21]

There are increasing numbers of videodiscs available for educational use. The Minnesota Educational Computing Corp. 1987 directory of educational videodiscs lists 360 discs, double the number entered in the 1986 edition.[22] Not all of these products were originally created for classroom use. Programs range from studies of outer space to visits to the Metropolitan Museum of Art. One product called *THE BIO SCI VIDEODISC* contains more than 6,000 still images, 2 motion sequences, maps, charts, and diagrams that can expand the typical information presented in biology textbooks. With documentation on biochemistry, cell biology, plant taxonomy, and zoology, the disc comes indexed by subject in hierarchical order and by numeric frame reference.[23]

More comprehensive efforts to develop courses on videodisc are underway. For example, the Texas Learning Technology Group[24] is developing a 160-hour, two semester, complete physical science curriculum that can be taught in grades 8, 9, or 10. The curriculum, using interactive videodisc technology, is in field test at participating district sites.[25]

Computer/Video Convergence

Compact disc video (CD-V), digital video interactive (DVI), and compact disc interactive (CD-I) are prototypes that combine computer technology and laser optical storage technology. The difference between them is the way data are encoded, accessed, and displayed. CD-V uses discs with 5 minutes of video and 20 minutes of music for viewing and listening on a home television set. (There are as yet no instructional applications of CD-V.) CD-I has no full motion video, but contains thousands of still pictures, plus graphics, sound, and data. It is also intended for the home market. Both CD-V and CD-1 will eventually come in stand-alone units, much like VCRs, which can be connected and played on standard television sets.

DVI, on the other hand, is used with an IBM-AT personal computer or equivalent. It is a fully digital compact disc, but with capabilities similar to the analog laser videodisc described above. Most important, DVI ". . . fully realizes the notion of video becoming computer-compatible. "[26] It can play up to 70 minutes of limited-resolution full motion color video on a computer screen, or it can play back picture, sound, and data (but with less video). With this new technology, video can be digitally stored and played back in real time. The fact that DVI stores images in digital form means that they can also be combined or edited.

[21] TALMIS reports approximately 6 percent of schools with videodisc; Quality Education Data, Inc., estimates 28 percent of the largest school districts with videodisc.

[22] Minnesota Educational Computing Corp., *Videodiscs for Education: A Directory* (St. Paul, MN: 1988).

[23] *Electronic Learning,* "Videodisc Includes Visual Biology Library," vol. 7, No. 2, October 1987, p. 81.

[24] The Texas Learning Technology Group is a consortium of 12 Texas school districts, the National Science Center Foundation, Inc., and the Texas Association of School Boards.

[25] Paula Hardy, director, Texas Learning Technology Group, personal communication, January 1988.

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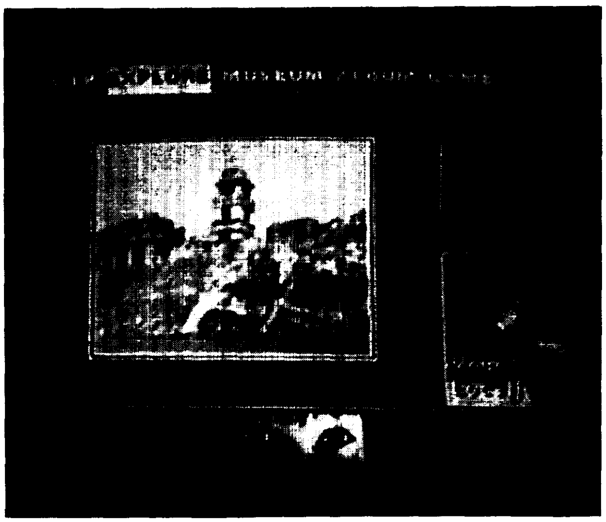

Photo credit: Center for Children and Technology, Bank Street College of Education

In this digital video interactive prototype, children can "walk" through the ancient Mayan archeological site, PALENQUE, and study items of interest as they come upon them. Dynamic eyes on the screen look left, right, up, or down as the children pan around their location on the site.

ADVANCES IN SOFTWARE[27]

The computers found in most schools have small memory capacity and slow processing times. At least 75 percent of the software titles listed in the Educational Productions Information Exchange were designed for the Apple-II line of computers, which still account for about 60 percent of the installed base in schools. The fact that these machines are sturdy, coupled with the constraints schools face in trading in and upgrading their inventories, means that software developers have been reticent to invest in sophisticated learning tools that require greater hardware capacities.

Hypermedia

Good examples of the kind of advanced software that could eventually make a difference in classroom teaching are hypertext and hypermedia. These systems represent an important breakthrough in making computers more compatible with human cognitive processes, because their storage of information is nonlinear, Just as human long-term memory consists of a complex web of associational links, hypermedia provides access to text, graphics, images, and in some cases, sound, without requiring users to specify in advance the order of access.[28] The INTERMEDIA project at Brown University is an illustration of hypermedia applied to education.[29] Users access an integrated set of text, graphics, editing, and scanning tools. Several different courses at Brown use these materials, which are linked via local area network. Hypermedia systems are substantially more complex than typical software programs, and require significantly greater computer memory capacity. Thus, while they represent a potential milestone in both the preparation of instructional materials and their application in classrooms, hardware requirements exceed the current capacity of most computers found in public schools. HyperCard, for example, Apple's recent entry into hypermedia software, was originally designed for business and only runs on Macintosh computers with at least one megabyte of random access memory (RAM).

Integrated Learning Systems

Another trend is toward greater machine control of lesson sequencing and monitoring of individual student progress. Some integrated learning systems (ILSs) include simulations and tutorials that go considerably further than electronic equivalents of drill and practice, and many cover complete curricula. At Juan Linn School in Victoria, Texas, an ILS developed by Education Systems Corp., serves 500 students a week. The software contains about 1,500 lessons in language, mathematics, and problem solving. The system manages instruction to each individual student in the school and records the progress of each student from day to day. Every child finds his or her name on the screen of a computer when entering the classroom. Although the individual computers are capable of working independently, they are usually linked in a local area network.

Videodisc Software, Compatibility, and Video Programming

Some examples of videodisc software suggest the potential for applications in education. For instance, the *National Air and Space Museum Archival Videodisc 2* contains 100,000 photographs of major air and space personalities, aircraft, balloons, airships, commercial airlines, air meets, trophies, military aviation aeronautical communications and equipment, museums, philatelic covers, and models. College *USA* shows more than 80 colleges and universities and describes their programs and facilities. *The Image Disc* archives 54,000 slides from a variety of sources, including 200 slides from the American Association of Physics Teachers repository. Not only are these databanks of images valuable for use in education and learning, they can also serve as raw materials for interactive programming.

For many reasons, especially the complexities of instructional design, creating an effective computer software package can be very expensive, costing from tens of thousands of dollars for individual programs

[27] See also ch. 6.

[28] Christopher Dede, "Empowering Environments, Hypermedia, and Microworlds," *The Computing Teacher*, vol. 15, No. 3, November 1987.

[29] Nicole Yankelovich et al., "Issues in Designing a Hypermedia Document System: The INTERMEDIA Case Study," *Multimedia in Education: Learning Tomorrow* (Cupertino, CA: Apple Computer, Inc., spring 1987); and Nicole Yankelovich et al., "Intermedia: The Concept and the Construction of a Seamless Information Environment," *Computer*, vol. 21, No. 1, January 1988, pp. 81-96.

to more than a million dollars for full courses of computerized instruction. Another factor contributing to high development costs of educational software is the incompatibility of computers found in schools. Software developed for the Apple 11 family will not run on Commodore, Tandy, or IBM computers. But in this regard too, there is a tendency toward convergence: some higher level operating systems allow programming in a "machine-independent" environment, so that programs can be sent from one hardware type to another with little or no change. These systems are generally too large to run on the computers commonly found in schools today; but there is reason to believe that continued research will yield an affordable solution to this problem of system integration. [30]

[30]See also ch. 6 for a brief description of the research program on system compatibility underway at the Institute for Defense Analyses.

Creating effective video programming, especially interactive video production, is very expensive. It requires complex instructional design and software programming, and multiple forms of video production.[31] For this reason, the major markets for interactive videodisc are in industrial and military training and medical simulations.

[31]It has been estimated that the average cost of producing a single interactive video program for industrial or business applications is $150,000. James A. Lippke, "Interactive Video Discs: Entering the Mainstream of Business," *Educational and industrial Television, vol. 19, No. 8, 1987,* p. 12. The Texas Learning Technology Group estimates that their physical science curriculum on interactive videodiscs will cost about $4 million to develop. Hardy, op. cit., footnote 25.

SUMMARY AND CONCLUSIONS

Interactive technologies for processing, storing, and communicating information have made their place in American business, science, and the military, and stand now at the doorway of the American public school.

More advanced computer logic and memory systems could allow students' computers to run several programs at once, to move information from one application to another, to communicate ideas to classmates and pen pals around the world, and to integrate the content of one lesson into another. Improved graphics, animation, and sound, as well as real-time video, could make subjects of study come alive. On-line multimedia libraries could provide information for class research projects. Increased access to other children, not only within the United States but all over the world, could broaden students' appreciation of different cultures. Experts from many disciplines, master teachers, and even community leaders and politicians could become available to inquiring classrooms. Telecommunications could allow students forced to remain home due to illness or weather conditions to connect with the teacher or with school programs to make up for lost time. Distance learning programs could support isolated populations of students who are underserved in certain subjects.

These technologies could also serve many other purposes and could become the center of new services to schools, teachers, and adults across the Nation. Software could be delivered on television signals. Instruction in many specialized areas of the curriculum could be broadcast to teachers and students, with exercises, testing, and help available through the telephone by voice or modem. Inexpensive video technology—small portable cameras that contain video recording devices—could be used by students to create audio/visual essays, or to gather images for use with computers. Students might combine pictures shot in their backyard with images received from databanks over the telephone, and written essays composed with word processors could incorporate graphs compiled using spreadsheet programs and computerized measurement devices.

In the words of a leading computer scientist, "The way computing has permeated the fabric of purposeful intellectual and economic activity has no parallel."[32] Information technologies have transformed the worlds of business, science, entertainment, the military, government, law, banking, travel, medicine, and agriculture. The question is whether they will make as deep a mark on classroom learning—and how.

[32]Abraham Peled, "The Next Computer Revolution," *Scientific American, vol. 257, No. 4,* October 1987, p. 57.

EPILOG

Most historians of technology would agree with Nobel Laureate Simon that the computer is no ordinary innovation. Indeed, the most profound question facing American society today is whether its institutions can adapt to a world that has changed more dramatically in the last 30 years than in the preceding 30 decades. Our schools are assigned the monumental task of arming young people to compete in this changing world: they are society's potters entrusted with the clay of children's minds. But there is abundant evidence that the potters' tools are rusted, and almost unanimous consensus that things must change.

Most educators believe that the new tools of the information age can be pivotal in shaping the American classroom to fit its ever-changing environment. For others—educators, technologists, and historians alike—there is a gnawing sense of deja-vu, a fear that relying on new technology to upgrade classroom learning signifies the triumph of hope over experience.

How will future historians judge the choices made today? Will their data consist mainly of teachers and students using new tools to push the frontiers of learning? Or will effective schools, in which computers and other technologies realize their full potential, always be the exception? To illustrate the critical crossroad at which we now stand, OTA has received permission to reprint the following excerpt from a recent paper by Shirley Malcom, a prominent authority on schooling and technology in America:

A Tale of Two Futures[33]

Raul Gomez walked in the door of his inner city middle school classroom rather down in the dumps. "Here we go again," he thinks. If it were not for the compulsory education laws and the possibility that his mother could be arrested if he were truant, he wouldn't bother to come at all. He spends a lot of his day sitting in front of the computer doing endless drill and practice.

To increase educational efficiency and to help Raul's teacher cope with 35 students, the district put computers in their classroom. Some of the children work on the computers while the teacher works directly with the others. For 14 students, English is not their native language. Among them, there are 7 different languages spoken. If he had to go through another set of practice problems and subject/verb agreements, he'd go crazy. Occasionally, just for a change of pace he'd deliberately answer a question incorrectly so he could see the funny little graphics built into "motivate the user." If he didn't get it right after a couple of times, "the solution" was explained to him. He had figured out other ways to solve the problems, but for some reason the computer never explained it his way. They both got the same answer, but he knew there must be something wrong with his way because the computer never did it like that.

Raul had thought computers were going to be a lot more fun. He first saw one at the Saltman's house, the family for whom his mother worked. He had gone with her during the summer to help with the yard work and had seen the games and the simulated science experiments. There was an electronic mail feature that had been set up to help team members keep in contact as they prepared for the international mathematics competition. But somehow, at his school it just wasn't the same. He asked Ms. Russell about those neat things he had seen at the Saltman's, but she had said that the students weren't ready for that yet. Besides, doing those things required more time on the computer and there were not quite enough machines to go around.

If only his family had the money to buy its own computer! But there was barely enough money to buy food and clothes and pay the rent for the four of them—Raul, his younger sisters, and his Mom. There was so much that he wanted to know about how the world worked, but in his class they never seemed to get to any of the exciting stuff-they always seemed to be getting ready for the next competency test, always having to cover more pages in the textbook. As soon as he could, he was going to quit school and go to work and help his mother with the girls. Maybe he'd get back to school one day. If there were more here for him he wouldn't leave, but it's just a waste of time. What good does it do his family if he knows the names of all the dead presidents?

"Shirley M. Malcom, "Technology in 2020: Educating a Diverse Population," paper prepared for the Conference on Technology in Education in 2020: Thinking About the Not-Distant Future, Harvard University, Educational Technology Center, Oct. 15-17, 1986. This conference was supported in part by OTA. This paper and others presented at the conference will be published in Nickerson and Zodhiates, op. cit., footnote 3.

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He had seen a TV program once about Mayan mathematics and about the sun dagger in the Southwest that native people developed to tell the arrival of the different seasons of the year. He asked his teacher about these things, but she said that they had to stay on schedule or they wouldn't cover the material in time for the science test.

Sonia entered her inner city middle school classroom elated. She had just "published" her first book, complete with illustrations. As soon as it had been bound, it would be put in the media center. Imagine that, Sonia Ramirez, AUTHOR. And to think, just 3 years before when she and her older brother and sister had come from Puerto Rico, she couldn't speak, read, or write English, and now she had a book in English and Spanish. The speech synthesis and translation features on the computer had really helped her develop proficiency in both languages. There were enough computers to go around and enough textbooks so that everyone could use them. Her book was about rain shadows. It was fun when you could do science, geography, English, Spanish, and art at the same time. She had to do a lot of work on her book at home, but that was all right. Sonia had been taking home a loaned computer since she had first entered school here. Computers are a big part of Sonia's life and the lives of her classmates. Her friend Hilda has a computer that speaks for her (and in a girl's voice!): Hilda is nonvocal because of cerebral palsy. Hilda has to use her computer for writing, too.

Sonia is learning to play the synthesizer in the school orchestra. The wide variety of software that she can borrow from the library (or that comes with the books) lets her look at all kinds of things that interest her. She and her classmates have developed software, too, which is included in the middle school computer network in their school system.

Sonia and Hilda are interested in birds. Their *Peterson's Field Guide* has a videodisc that goes with it so that they can study the birds in flight, listen to the songs and learn more about their life histories. It really helps to be able to go back and forth between similar species and to have the differences between them highlighted.

Raul and Sonia live in two very different futures. Raul's future was created by extrapolating from the present: the present trends in education, the present educational goals for poor, disadvantaged, and minority students, the present way the technology is used in educating these students. For Raul, overall trends in the technology matter very little when he has so few appropriate tools for his education, and when no concerted effort has been made to address his educational needs. Differences in the educational use of technology further separate the worlds of the Gomez and the Saltman families. On the other hand, Sonia Ramirez has been empowered by education, and the technology has made that education more meaningful and more accessible. At present, Raul's future is more probable though not very desirable. Achieving Sonia's future will not be easy.

Photo credit: Neldine Nichols, Wisconsin Department of Public Instruction

What kind of future will we choose for our children?