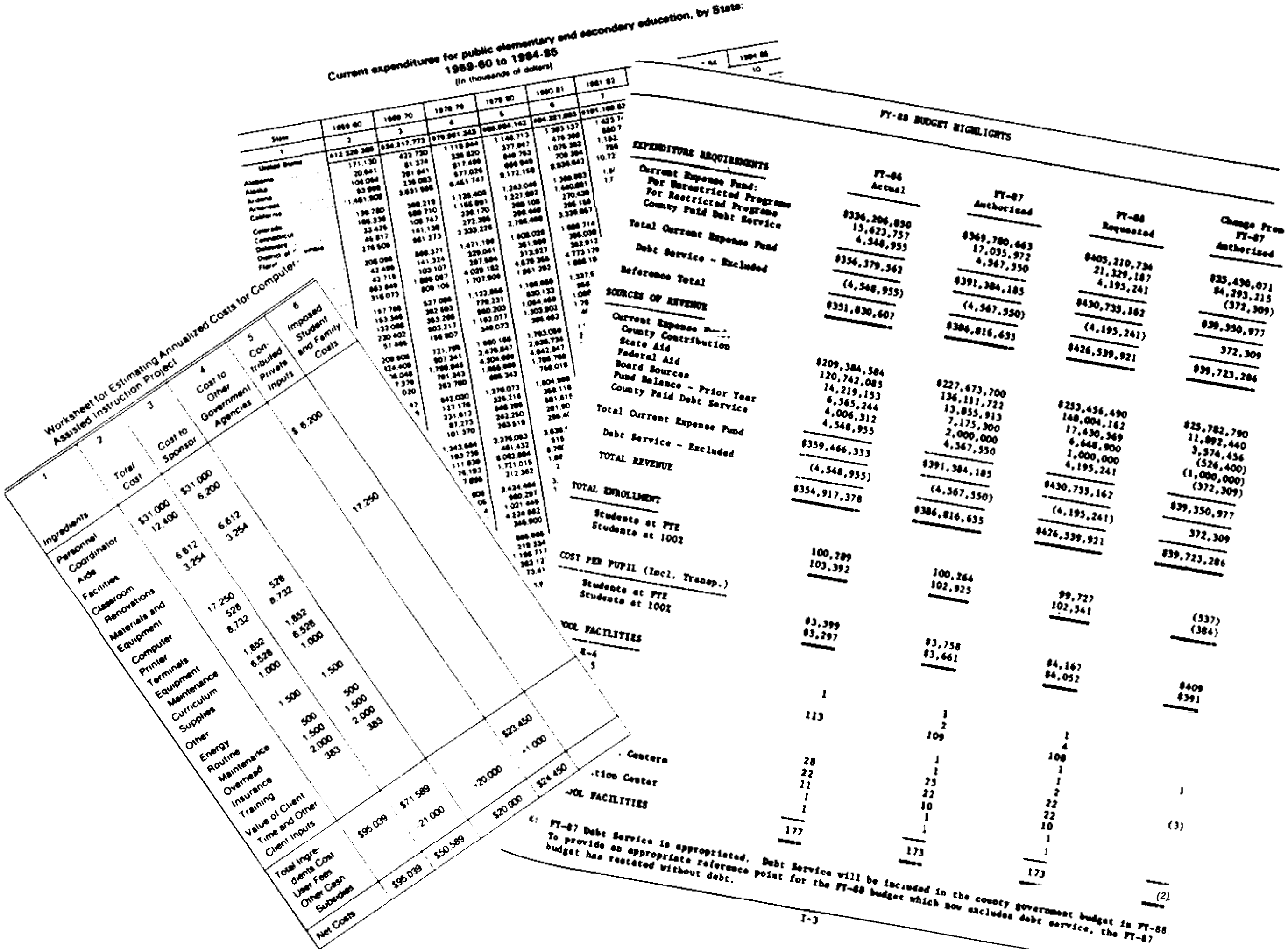
Chapter 4

Cost-Effectiveness: Dollars and Sense



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INTRODUCTION AND FINDINGS

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

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

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

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

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

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

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

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

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

ESTIMATING THE COSTS OF ALTERNATIVE INSTRUCTIONAL TECHNOLOGIES

An Illustrative Case

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

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

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

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

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

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

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

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

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

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

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

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

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

The Cost to the Nation: Two Scenarios

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

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

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

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

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

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

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

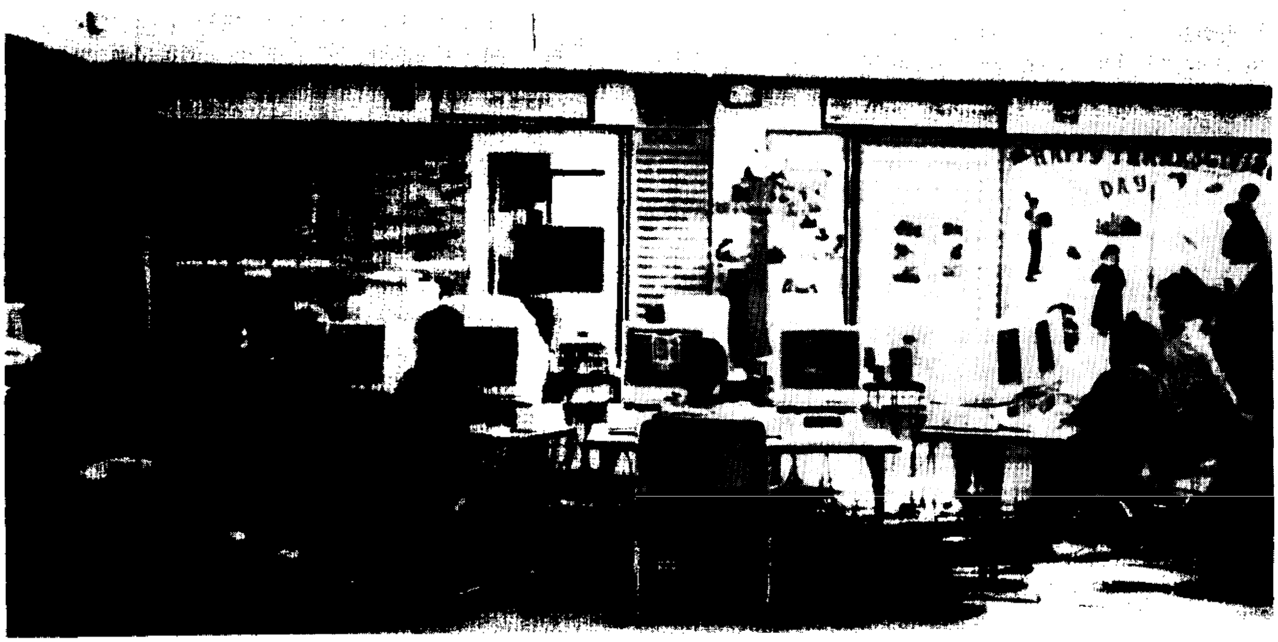


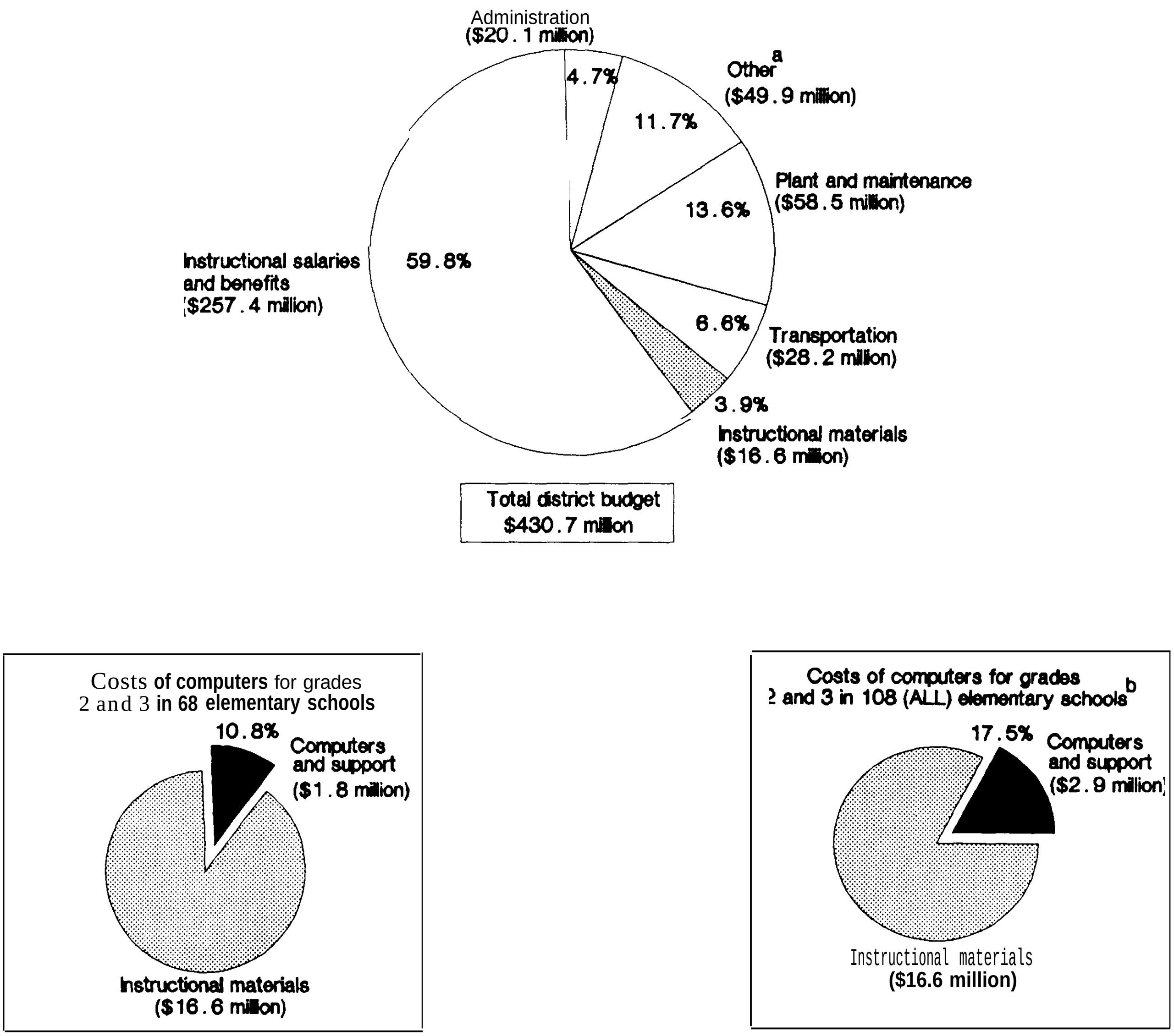
Photo credit: ***Massachusetts Institute of Technology***

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

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

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

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



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

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

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

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

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

This figure is but a tiny fraction of the gross national product (over $4 trillion), and a seemingly insignificant 3 percent of total U.S. expenditures on public elementary and secondary schools. However, of the $137 billion currently spent on public education, about $85 billion is budgeted for instruction, of which instructional salaries and benefits account for at least 85 percent. OTA has no evidence that computer technologies have displaced teachers; it is important to consider the budget implications of the new learning tools holding personnel costs constant. As shown in figure 4-2, the $4.2 billion annual cost for this massive infusion of new equipment would represent more than 30 percent of the amount currently spent nationwide on instructional materials.

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

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

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

SOURCE: Office of Technology Assessment, 1988

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

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

COST-EFFECTIVENESS [8]

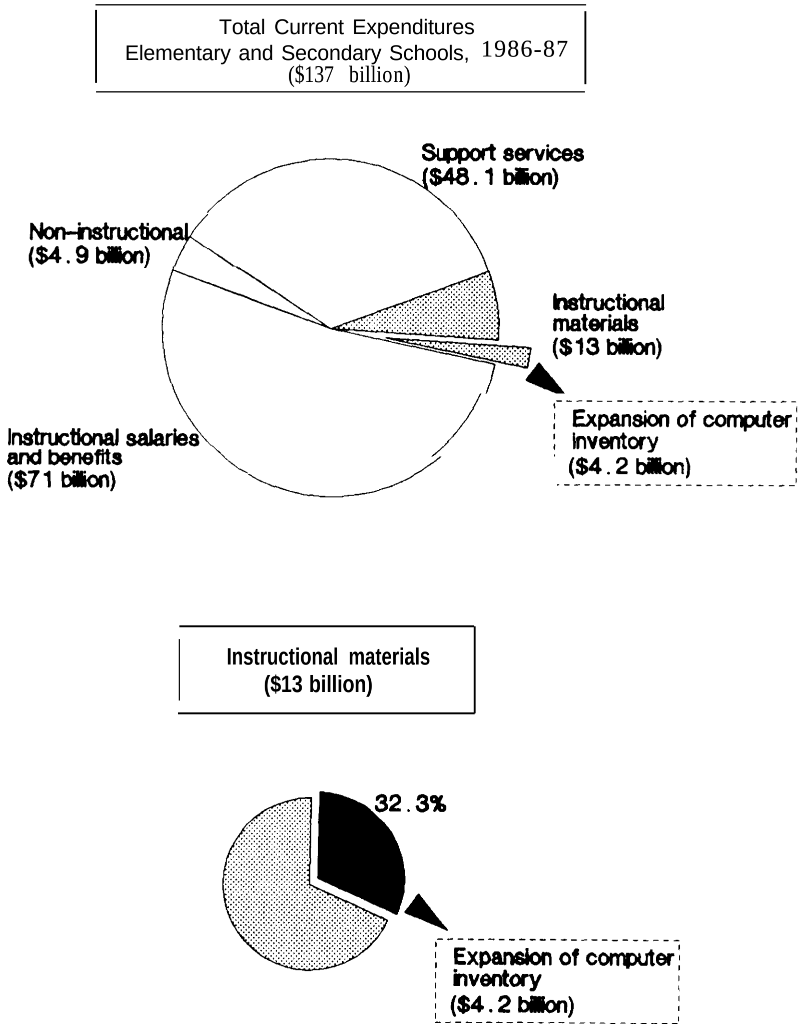
Political and Methodological Considerations

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

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

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

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



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

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

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

Basic Principles of Cost-Effectiveness Analysis[10]

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

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

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

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

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

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

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

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

[9]See Richard Murnane and Richard Nelson, "Production and Innovation When Techniques are Tacit: The Case of Education, " *Journal of Economic Behavior and Organization, vol. 5, 1984,* pp. 353-373.
[10]This section is drawn from Levin, Op. cit., footnote 4.

[11]Dean Jamison et al., "Cost and Performance of Computer-Assisted Instruction for Education of Disadvantaged Children," *Education as an Industry,* J. Froomkin et al. (eds.) (Cambridge, MA: Ballinger, 1976).
[12]Henry Levin et al., "Cost Effectiveness of Four Educational Interventions," IFG Report No. 84-Al 1, Stanford University, 1984. See also Henry Levin and Gail Meister, "Is CAI Cost-Effective?" *Phi Delta Kappan, vol. 67, No. 10, 1986.*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Cost-Effectiveness Analysis in Practice[20]

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

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

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

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

"Ibid., p. 33.

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

Box 4-A.—Arkansas Project IMPAC

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

[a]Projections assume four 55-minute periods of mathematics instruction provided to 20 students in each period for 197 school days.
[b]Increased annual costs projected for adjunct computer-assisted mathematics instruction.
Abbreviation: CAI = computer-assisted instruction
NOTE: All costs are in 1985 Canadian dollars.
SOURCE: D. Hawley et al., University of Oregon, Center for Advanced Technology in Education, "Costs, Effects and Utility of Microcomputer-Assisted Instruction," Technical Report, 1986, p. 21.

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

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

Abbreviation: CAI = computer-assisted instruction

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

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

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

NOTE: Costs are in 1985 Canadian dollars.
Abbreviation: CAI = computer-assisted instruction

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

CONCLUSIONS AND POLICY DIRECTIONS

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

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

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

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

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

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

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

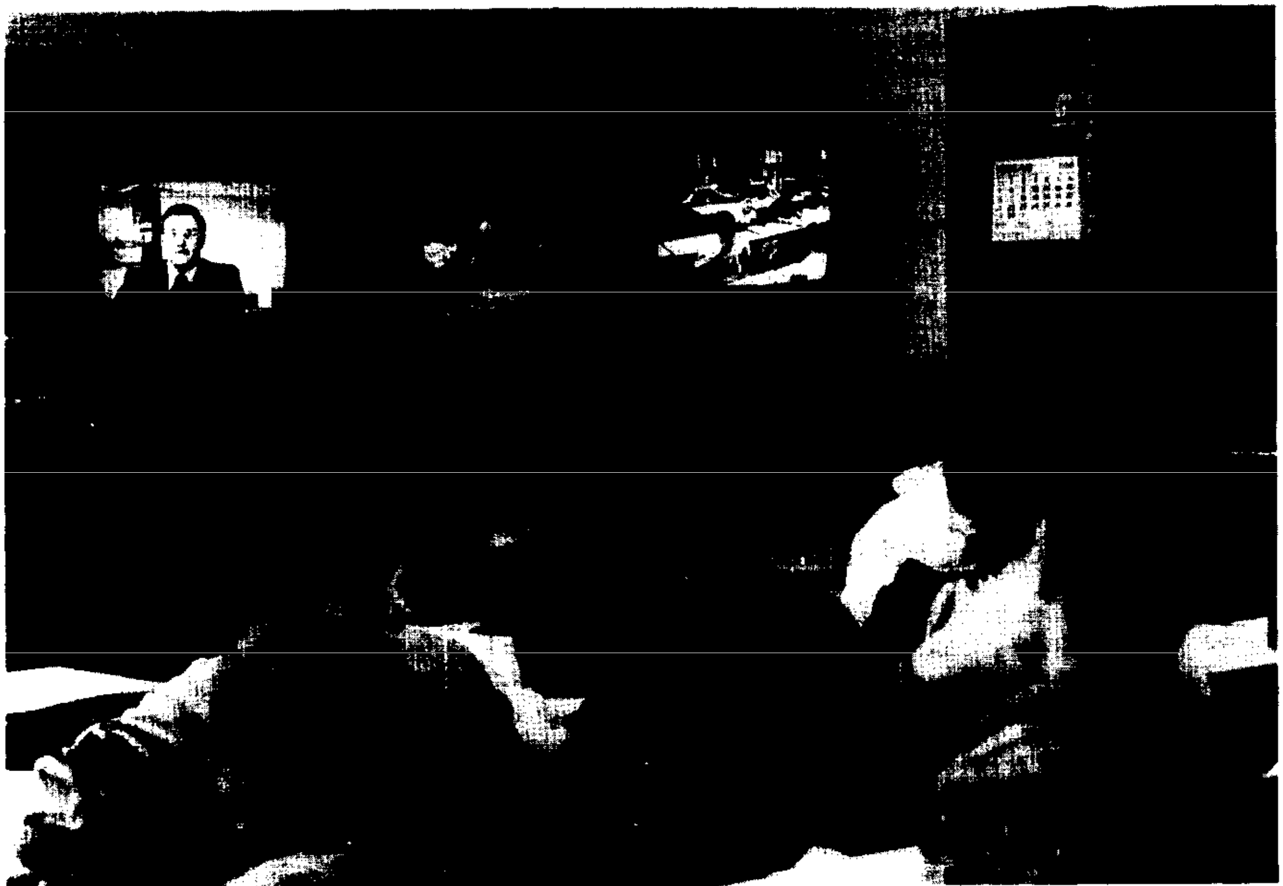


Photo credit: Bill Davie, Trinity Productions

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

Government can encourage the use of this decisionmaking tool in the following ways:

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

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

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