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Abstract

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An Evaluation of the Costs of Computer-Assisted Instruction

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Various educational technologies such as educational radio, educational television, and computer-assisted instruction (CAI) have been proposed in recent years as partial solutions to both the problems of rising educational costs and the failure of the educational system

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to impart basic skills to disadvantaged youngsters. The logic of the cost-saving aspects of educational technologies is conditioned heavily upon the assumption that the high labor costs of education can be reduced by substituting relatively lower cost capital inputs without sacrificing educational results. The view that certain educational technologies can improve the quality of educational results for disadvantaged youngsters is premised on the fact that such approaches as CAI can be individualized to take account of the particular strengths and deficiencies of the learner.

These assumptions about the comparative advantages of replacing some portion of traditional classroom instruction with a more capital-intensive educational technology would seem especially pertinent to the case of CAI. Recent technological breakthroughs in computers, particularly the advent of minicomputers and inexpensive memory devices, have both expanded the capability and flexibility of computers with respect to their instructional applications and reduced their costs considerably. Also, CAI permits a large variety of methods for individualizing instruction according to the actual performance of the learner. For example, a computer-based curriculum can be designed to provide automatically additional problems in any area in which a student is not performing according to some preset standard, or it can be arranged in particular sequences of instructional tasks that emphasize a student's special instructional needs.

Despite the promise of educational technology in improving educational outcomes and reducing costs, there is little supporting evidence of a rigorous nature for either the relative costs or educational results.[1] In response to this evaluative deficiency, the National Institute of Education decided to undertake an experimental study of CAI in order to evaluate its effects on the improvement of reading, language skills, and arithmetic operations of elementary school children. The experiment was initiated in the fall of 1976 on the basis of a research design that was prepared by the Educational Testing Service (ETS) and implemented in the Los Angeles Unified School District (LAUSD). Known as the ETS/LAUSD Study on Computer-Assisted Instruction and Compensatory Education, the study was intended to ascertain the effects of a particular computer-based instructional system and curriculum on student test scores in three subject areas as well as the costs for replicating this particular system.

1. The best studies in this area are Jamison et al. (1976 and 1970) with respect to CAI. However, cost effectiveness analyses of other technologies can be found in *Instructional Science* (1975). See Carnoy and Levin (1975) for a critique of the methodologies of these studies.

With respect to educational effectiveness, the research design was constructed in order to ascertain the effects on test scores in reading, arithmetic, and language arts of the "drill and practice" curriculum of the Computer Curriculum Corporation (CCC) among students at different elementary grade levels. The evaluation was arranged to determine the effects of 10-minute daily sessions of CAI on student achievement. Comparisons of test results for disadvantaged students are being made according to the number of daily sessions of CAI, the subjects in which CAI sessions were given, and the number of years in which students received CAI. The studies of effectiveness are intended to reveal the educational impact of this particular CAI approach across subject areas, grade levels, amounts of exposure, and different types of students (race, sex, ethnicity, socioeconomic status, and so on).[2]

The evaluation of the effectiveness of this CAI approach does not address the issue of costs. Given its focus on the educational needs of disadvantaged students, two questions arise pertaining to costs. The first question is based upon the assumption that funding for special educational services for disadvantaged students is derived primarily from special categorical aid for that purpose, such as that received under Title I of the Elementary and Secondary Education Act of 1965. Therefore, it is important to know if CAI can be provided within the budget that is available for these compensatory educational services for disadvantaged youngsters. Second, it is important to know if the CAI approach can improve the educational proficiencies of disadvantaged students at costs that are similar to or less than those associated with other instructional alternatives.

The first issue is one of cost feasibility. If the costs of this CAI approach exceed the funds available for instructional purposes for disadvantaged youngsters, it will not be within the boundaries of feasibility. The second issue is one of cost effectiveness. Even if CAI can be provided within the present budgets for compensatory education, it should be adopted only if it provides better results relative to its costs than do existing alternatives.

Cost feasibility can be examined by evaluating the costs of CAI and ascertaining whether it is within the budgetary allocations provided for compensatory education by Title I of the Elementary Secondary Education Act of 1965 or by various state and local compensatory programs. Cost effectiveness comparisons can be made only by comparing both the results and the costs of the CAI approach with the results and costs of other instructional alternatives.

2. Preliminary findings are reported in Holland, Jamison and Ragosta (1980).

Although this study can establish the CAI costs, it is not designed to pursue its effects. However, the overall CAI experiment on which this study is based will provide rather sophisticated estimates of test score results associated with student exposure to different amounts of CAI in different subjects. Accordingly, the costs that are estimated in this study can be combined with the experimental effects of CAI for cost effectiveness comparisons with other instructional approaches.

In this paper we will estimate the replication costs of the CAI approach used in the ETS/LAUSD experiment, that is, the cost of replicating that system in other school settings. In doing this we will limit those costs only to ones that are associated with the delivery of CAI while omitting costs that are tied uniquely to the experimental status of the present system. That is, we are concerned with the costs of introducing this particular CAI approach into other schools outside of the present experimental situation. At the same time, we are concerned with modifications of the experimental CAI that might affect costs. In particular, there exists a later version of the present computer that is more advanced. The cost implications of the newer computer will be examined after exploring the costs of replicating the present experimental approach.

The organization of this paper will be as follows. First, a brief description will be given of the present CAI system and its configuration in the ETS/LAUSD schools. Second, a short presentation will be made of the costing methodology that will be used in this study. Third, cost estimates for replicating the present CAI system will be made. Fourth, the cost feasibility of adopting this system of CAI for compensatory education will be evaluated as well as the cost implications of a more advanced system.

THE SYSTEM OF COMPUTER-ASSISTED INSTRUCTION

The purpose of this section is to provide a brief summary of the implementation of computer-assisted instruction in the ETS/LAUSD study. This description is of special importance because each CAI approach and installation is associated with different resource costs and effects. The ETS/LAUSD experiment is based upon the use of a particular computer system and curriculum that have been utilized in a specific way. Therefore it is important to provide some description of the system and its application. It is equally important to bear in mind that the evaluation of this particular CAI approach with respect

to costs or educational effects cannot necessarily be generalized to other CAI approaches. Rather, all results will be limited to the specific CAI application that is being evaluated.

The heart of the ETS/LAUSD instructional approach is the use of the A-16 computer for providing drill and practice instruction for the students. Each student is seated at a terminal that consists of a keyboard reasonably similar to that of a typewriter and a cathode ray tube (CRT) that is similar to a television screen. Each A-16 can be used to service up to 32 terminals simultaneously. The A-16 contains curricula for all elementary grades for each of the three subject areas: mathematics, reading, and language arts. Each session lasts for 10 minutes, although some students may be assigned to undertake more than one session per day.

Each student signs in at his or her terminal and begins the session where he or she had left off in the previous session. A problem is displayed on the CRT, typically in a multiple-choice or a "fill in the blank" format. For example, the student might be given a problem in arithmetic operations such as vertical addition or subtraction, and he or she must type in the solution. Or, the student might be asked to fill in the correct form of a verb in a sentence. If the answer is correct, an asterisk is displayed on the CRT; if it is incorrect, the student is so informed. In either case, a new problem is displayed. When a student achieves adequate proficiencies on a particular part of the curriculum—as evidenced by a high enough proportion of correct answers—the system provides problems of the same type at a higher level of difficulty. The curriculum is not designed to introduce new material as much as it is to provide an opportunity to practice concepts that have already been taught.

There are two principal personnel who assist the students in working with the CAI system. A *coordinator* is responsible for the entire operation in a particular school including the scheduling of students; the provision of summaries of progress for each class to the classroom teachers (available from a printer that is attached to the A-16); the security and condition of the equipment (such as ensuring that the equipment is working properly and calling maintenance personnel when necessary); and the overall supervision of the students in working at the terminals. The coordinator is assisted by a *teaching aide* who monitors the students and answers their questions or assists them when they seem to be having difficulties.

The ETS/LAUSD experiment was based upon results from four experimental schools and two comparison ones that did not receive CAI. Two of the four experimental schools were large enough

to utilize an A-16 with a full complement of 32 terminals. The other two schools had smaller student populations, so they shared an A-16 through the use of telephone lines and special equipment (multiplexer and modems). Each of these schools had 16 terminals installed so that the shared A-16 was also attached to a total of 32 terminals. The CAI rooms had to be modified to accommodate the special configuration of equipment as well as to assure security and an appropriate climate of temperature and humidity for maintaining the computer.

COSTING METHODOLOGY

The concept of costs typically tends to be confusing to evaluators. Often the tendency is to review budgets to estimate the costs of a particular project. But the costs that one finds in a budget or accounting statement are often in error or are misleading for a number of reasons. First, budgets typically show estimated costs rather than actual ones. To the degree that there are discrepancies between the real costs and the estimated ones, budgetary costs will not be accurate. Second, budgetary costs often provide costs of resources that will be used over different time periods. For example, although salaries in a given year will cover the labor services during that period, a piece of equipment may be utilized for many years. Yet the cost will be assigned only to the year in which the equipment was purchased, whereas it should be divided over the entire period of use on an annualized basis. Third, costs of contributed inputs are not included in budgets, confusing the question of what are the true costs of a project with the question of who paid the costs. Finally, some budgetary costs are distorted because they represent special purchases or transactions that do not reflect the true market values of the transactions.

A more appropriate method for estimating costs is to use the ingredients method.[3] This method is based upon the assumption that whenever resources that have alternative uses are allocated to a particular activity, those resources have a cost to society. The cost is equivalent to the value of the resources in their most productive application. The most typical way of estimating these costs is to use the market value of the resource. Further, in order to obtain annual

3. Virtually all the issues discussed here are reviewed methodologically in Levin (1975). The best application of costing methodologies to instructional technologies is Jamison et al. (1978).

costs of an alternative, the costs of various ingredients that are utilized over more than one year are "annualized" in order to charge to each year only the costs for that period (rather than assigning the entire cost to the year of the purchase). Because there are sources that can be used to evaluate the techniques of cost analysis within this framework, we will not discuss these techniques in detail here.[4]

The following steps are necessary for estimating costs, using the ingredients approach.

1 List all ingredients or resources required for implementing the instruction.
2 Estimate the costs of each ingredient on the basis of actual costs or estimated market values.
3 Convert costs into the appropriate categories for analysis such as annualized costs, average costs, or marginal costs.

In this particular case we wish to estimate the costs for replicating the ETS/LAUSD system of CAI in other educational settings, and we wish to evaluate costs under different organizational arrangements.

CAI Ingredients and Their Costs

Before enumerating the various ingredients of the CAI system and their costs, it is useful to mention the bases on which ingredients might be classified as well as the sources of the cost information. The classification of ingredients can be done in any way that is functional to the questions that will be raised. For example, one can classify ingredients under personnel, facilities, equipment, and miscellaneous categories. Or one can set out categories of ingredients that represent fixed investments as well as those that represent recurrent cost items. The main criteria are that all ingredients are accounted for in the classification approach, and that the ultimate categories are useful for analytical purposes.

The derivation of cost information for the various ingredients will be done in a number of ways. Where budgetary and accounting information are appropriate they will be used. Where such cost data are inappropriate or misleading, other methods of obtaining costs will be utilized. In all cases the sources of the cost information will be specified as well as the methods of cost estimation. In this way the reader can ascertain how the costs were derived; it is also possible to modify

4. Ibid. This paper will not include student time as a resource because it is difficult to place a value on this dimension. However, alternative instructional strategies with mostly different demands on student time should take this component into account.

the assumptions on cost estimation to determine the sensitivity of costs to different premises.

COST ESTIMATES

For purposes of cost estimation, the ingredients of the CAI approach will be divided into six categories: (1) Facilities and Equipment; (2) Training; (3) Personnel; (4) Curriculum Rental; (5) Maintenance; and (6) Miscellaneous Factors. Each of these will be evaluated, in turn, and they will be combined in analyzing the overall costs of CAI.

1. Facilities and Equipment

Any CAI approach has the obvious requirement of the equipment needed as well as the facilities needed to provide CAI. In the case of the Los Angeles experiment, the equipment for a school using a single A-16 computer, 32 terminals, and a printer is estimated at about $121,000. The complete breakdown for each type of equipment is shown in Table 1. That table also presents the estimates of facility costs. These include the cost of construction of a normal

TABLE 1. FACILITIES AND EQUIPMENT, 1977-1978.

Facilities		
Cost of construction of a CAI room[a]	$ 50,000	
Renovation cost[b]	18,500	
		$ 68,500
Equipment[c]		
One A-16 computer system	$ 68,120	
installation	3,000	
32 Hazeltine Modular I terminals at $1,440/ea	46,080	
delivery at $63/ea	2,016	
One Hazeltine Thermal Printer	1,950	
delivery	23	
		$121,189
Total		$189,689

a. It was reported from the Educational Housing Branch in Los Angeles that to replace space in which the CAI experiments are housed in the 1979 construction market would cost approximately $50,000 per room.

b. The renovation costs include counters, intrusion alarm, carpentry, paint, electrical work, window grilling, air conditioning, and the labor involved.

c. These costs are derived directly from the CCC contract.

instructional classroom as well as the renovations that must be made to accommodate CAI.[5] Renovation costs include special carpentry work, protective devices, electrical work unique to the CAI installation, and air conditioning. In 1977-1978 the facilities costs were estimated to be about $68,500, and the total value of the equipment and facilities was assessed at almost $190,000 per school.

However, we are not concerned with the total costs of these ingredients as much as we are with their annualized costs. That is, a classroom is assumed to have a life of 25 years, so that only about 1/25 of the cost should be allocated to a particular annual period.[6] The renovations are assumed to have a life span of 10 years, and the equipment is estimated to have a life span of 6 years.[7] In each case we must use a standard approach to convert the overall costs into annualized ones, where the annualized cost represents the depreciation and interest costs foregone on the investment for each year. The annualized cost will depend on three factors: (a) the overall investment cost; (b) the life of the facilities or equipment or the amortization period; and (c) the rate of interest on the investment that is foregone.[8]

Table 2 shows the annualized values of facilities and equipment costs with the specific assumptions about the amortization period and three different interest rates. The 1979 rate of interest on U.S. treasury bonds of about 10 percent seems to be a reasonable figure for calculating foregone interest on the investment. On that basis the annualized cost of facilities is about $8,524 and that of equipment is about $27,873. Thus the estimated cost of facilities and equipment is about $36,397 per year.

2. Training

Training costs are composed of two types: direct and indirect. The direct costs are the most obvious ones, consisting of such items as sal-

5. As school enrollments decline, it is common for some observers to question whether any cost should be attached to newly available classrooms that are no longer needed to service regular enrollments. However, such facilities are not costless as long as they have alternative uses. In fact, there are a large number of alternative uses as evidenced by the expansion of special education programs, rental of rooms to other public agencies, or the closing of schools and their rental or sale.

6. The useful life of school facilities is taken from estimates by LAUSD administrators.

7. CCC staff gave us a figure of 6-10 years depending on level of utilization and assessments of technical obsolescence. We have used the 6-year figure because of the very intense level of utilization of the equipment. However, extending the estimated life to 10 years would have the effect of reducing the overall instructional costs by no more than 2-3 percent.

8. See Levin (1975) and Jamison et al. (1978).

TABLE 2. ANNUALIZATION OF FACILITIES AND EQUIPMENT COSTS, 1977-1978.

Cost Categories	*Amortization Period (years)*	*Cost*	*Annualized Cost*		
			0%	*10%*	*15%*
Facility					
Construction of a CAI room	25	$ 50,000	$ 2,000	$ 5,508	$ 7,750
Renovation	10	18,500	1,850	3,016	3,682
Facility subtotal		$ 68,500	$ 3,850	$ 8,524	$11,432
Equipment[a]					
Equipment subtotal	6	$121,189	$20,198	$27,873	$31,994
Total			$24,048	$36,397	$43,426

a. Refer to Table 1 for the details. The amortization period for all computer-related equipment is assumed to be 6 years.

aries of instructors and costs of materials. The indirect costs refer to the value of the time of the trainees. In the case of the ETS/LAUSD project, the direct costs of training were included in the costs of equipment by CCC. However, the indirect ones had to be borne separately. According to the experience of CCC personnel, it is usually sufficient to provide workshops of 1.5 days for coordinators and 0.5 day for teachers. The cost for each teacher and coordinator will vary according to experience and training and the salary levels in the particular school district. However, in Los Angeles it appeared in 1977-1978 that salaries and fringe benefits averaged about $20,000 for a school year that was not more than 200 days. This suggests that a pay rate of about $100 per day is an appropriate basis for calculating costs of the time required by teachers and coordinators to obtain training. For 40 teachers to an elementary school, the indirect costs of teacher training are about $2,000 for a half-day workshop and about $150 for a 1.5-day workshop for the coordinator. Thus, the total estimated indirect costs of training are about $2,150.

One question that arises is how this figure translates into an annualized cost. It is unlikely that training costs of this magnitude would be required for each year, for the carryover of trained teachers and coordinators from year to year would be rather high. Yet any turnover of teachers will require some training to take place each year, even if it is merely the coordinator taking the teacher away from his or her classroom duties for half a day for instruction. For example, with a turnover rate of 10 percent per year, about 4 new teachers would have to be trained each year at a cost of about $200. In fact, after the first year this would be the only cost of training as well as the interest foregone on investments for training in previous years. If we use those two components to estimate costs, the total indirect training costs would be 10 percent of the previous investment in training per year plus the costs of training new teachers. On the average, 10 percent of the training investment over a 6-year period would be about $250 and the indirect cost of training 4 new teachers a year would be about $200 for a total of $450 a year. Whatever the assumptions are about the costs of this component, the overall cost implications are so small that they will have little impact on the total cost calculations.

3. Personnel

Personnel ingredients for the CAI demonstration include administrative resources, the CAI coordinator, two teaching aides, and substitutes to cover the absences of the coordinator, as shown in Table 3.

TABLE 3. ANNUAL PERSONNEL COSTS, 1977-1978.

Administration	$ 1,965
CAI coordinator	22,500
Fringe benefits on above at 16.7%	4,086
Two teaching aides	5,220
Substitutes	780
Total	$ 34,551

The function of the administrative personnel is to negotiate the contracts with the companies that maintain the equipment, to arrange payments, and to provide general financial and logistical administration of the project. The annual personnel costs for this function in 1977-1978 were estimated at $1,965 on the basis of previous experience of the Los Angeles schools with these types of projects.

The CAI coordinator is responsible for the overall functioning of CAI including scheduling and coordination of instruction, reports to teachers on student progress, and monitoring of equipment functioning and maintenance. Especially important is the latter function, because equipment failures result in the loss of instructional sessions. Accordingly, the coordinator must be aware of problems and the methods of getting them solved by the appropriate maintenance personnel. Further, the coordinator must work closely with classroom teachers to integrate the drill and practice sessions of CAI with classroom work.

In the ETS/LAUSD case, the coordinators were so carefully chosen and so well trained that they needed little administrative supervision from the school principal or other school administrative personnel. Whether this high level of initiative and independence can be maintained in a replication is problematic. However, based upon the success of coordinator autonomy in ETS/LAUSD, we have not indicated any supervision in the cost estimates. The cost of the coordinators can be determined directly by calculating salaries and fringe benefits. The salary component was estimated at $22,500 and the fringe benefits for that portion of the administrative costs and the coordinator were $4,086. Fringe benefits do not apply to the other personnel categories because of their part-time nature.

Teaching aides monitor the performance of students and assist them in understanding the CAI problems and in solving them. Essentially they wander among the students, looking for situations in which assistance or supervision is needed. Their rate of pay in 1977-1978 was $4.35 per hour, and it takes two teaching aides working

about 600 hours each school year to assist in a CAI room with 32 terminals. This particular arrangement has been considered highly satisfactory by the Los Angeles coordinators. The total cost per CAI room of the two aides is about $5,220 a year.

The final personnel cost is related to the need for substitute teachers to undertake the coordination functions if the regular coordinator is ill. Under the Los Angeles arrangements, a teacher or coordinator can receive up to 12 days a year in paid sick leave. Therefore, provision for up to 12 days of substitute teaching at about $65 a day would cost about $780 per year. Based on these amounts, the personnel costs per year for 1977-1978 totaled about $34,551.

4. Curriculum Rental

The curricula that are used for the CAI approach are rented from CCC, the company that provided the A-16 system. The rental covers the cost of using the three sets of subject curricula in mathematics, reading, and language arts. The cost of the rental is set at $204 a year for each of the 32 terminals in a CAI room, for an annual total of $6,528.

5. Maintenance

The provision for maintenance of the equipment is arranged through contracts with firms that specialize in such care. Although some of the maintenance is routine and periodic, a major requirement is services of an emergency nature to repair malfunctions. The annual cost of maintaining the A-16 computer in 1977-1978 was $6,120 a year; each of the 32 terminals has a maintenance cost of $300 a year, or $9,600 for all terminals in a CAI room; and the thermal printer has a maintenance cost of $360 a year. The total cost of maintenance is about $16,080 a year.

6. Miscellaneous Factors

Miscellaneous cost factors include insurance, supplies, and the costs of energy and routine maintenance of the classroom. The appropriate insurance costs are those that are incurred directly from the CAI facility and equipment, including the additional insurance costs for theft, fire, and liability. Of these components, it appears that liability insurance is largely unaffected, and the impact on fire insurance costs is not readily ascertainable. However, the additional theft insurance for the equipment was estimated by the Los Angeles school authorities at about $3,000 a year for the computer, 32 terminals, and printer. The use of only the theft component may understate slightly the true insurance costs by omitting the fire com-

ponent. However, the overall omission is likely to have a relatively small effect on total costs, for insurance represents a very small relative cost item.

Supplies, energy, and routine maintenance of the classroom contain many items. Supplies typically include pencils, paper, books, and paper for the printer. Energy and telephone costs and facility maintenance refer to the telephone in each classroom that is necessary for rapid access to maintenance personnel and CCC in case of breakdowns; normal heating, lighting, and power for the equipment; and routine cleaning and maintenance of the classroom. Taken together, these are estimated at about $3,000 per year. Again, even substantial changes in this amount (for example, 50 percent) would have little effect on overall costs per student session because of the relatively small magnitude of costs for the category. Each classroom is capable of providing a daily session on an annual basis for over 700 students, so an error of $1,500 is only about $2.00 per session.

Summary of Annualized Costs

The annualized costs in 1977-1978 for a 32-terminal classroom utilizing the CCC A-16 system can be summarized in the following tabulation.

Facilities and equipment	$36,397
Personnel	34,551
Training	450
Curriculum rental	6,528
Maintenance	16,080
Miscellaneous	6,000
Total	$100,006

It appears that in 1977-1978 it cost about $100,000 a year to provide a classroom, personnel, and equipment for servicing 32 terminals with this particular approach to CAI.

Average Cost per Session

It is important to know the cost per session on an annual basis for each student. That is, what is the cost for providing one daily session of 10 minutes of drill and practice for a full school year to each student? The reason that this particular cost figure is important is that it would enable us to ascertain the cost feasibility of this approach to CAI as a method of providing compensatory education to disadvantaged youngsters by comparing the amount per session with the average amount of compensatory funds provided by the federal gov-

ernment under Title I of the Elementary and Secondary Education Act of 1965.

The cost per session depends on the number of daily sessions that can be provided by the CAI system on an annual basis. This depends not only on the length of the session but also on the organizational capacity and time required to process each group of student users. That is, there must be time between the end of one 10-minute session and the beginning of the next for one group of students to sign off the system and return to class, while a new group arrives, is seated, and signs in. Finally, the number of sessions will also depend upon the overall reliability of the equipment and its operability during school hours.

In theory, the system could be used for up to 6.5 hours a day during regular school hours, if sessions began at 8:30 A.M. and proceeded to 3:00 P.M. with no interruptions for lunch. In practice, this would be difficult to do organizationally, for time is needed both at the beginning and at the end of the day to accomplish record-keeping and other instructional tasks associated with CAI. Further, it would be difficult to coordinate classes around the lunch period, and a relief coordinator would be needed during that period. With respect to the number of sessions per hour, even 5 sessions of 10 minutes each provide only about 2-minute transition periods. Accordingly, there are clear limits on the numbers of sessions that can be accommodated. Based upon the actual records for the ETS/LAUSD system, it appeared that the range varied from 21 sessions to 25 sessions per day, with a median of about 23 sessions. On the basis of these experiences, we can estimate the cost per daily session per student for a school year.

Number of Sessions per Day		*Annual Cost per Daily Session*
Per Terminal	*For 32 Terminals*	
21	672	$148.80
23	736	135.90
25	800	125.00

Depending on the number of sessions per day for each terminal, a configuration using the A-16 and 32 terminals in a single classroom can accommodate from 672 to 800 sessions a day. Assuming that the most probable estimate is the median of 23 sessions a day per terminal, 736 sessions can be provided. By dividing the number of sessions by the $100,000 estimated annual total cost for this CAI configura-

tion, it appears that the annual costs for a daily session of 10 minutes can vary from about $125 to almost $150 per year for one daily session of CAI. The estimate for 23 sessions a day at $135 is probably the most reasonable one.

Cost Estimate for the Shared System

Before comparing that cost with the level of funding available for compensatory education, it is important to estimate the annual cost per daily session when two schools share an A-16 system. This situation presents itself when there is not an adequate student enrollment base in a particular school to accommodate about 700 daily sessions. It can also be evident in situations where only a particular grade level utilizes CAI. Of course, by providing multiple daily sessions (for example, two sessions a day), an A-16 can be utilized to full capacity by even 350-400 students. However, in the Los Angeles situation, the design of the CAI experiment meant that in two participating schools there were not adequate students assigned to CAI to fully utilize a 32-terminal system in each school. This situation provides us with the opportunity to ascertain the costs of a shared CAI computer.

The basic configuration for the shared system was that the A-16 computer and 16 terminals were placed in one school, and the other 16 terminals were placed in a "sister" school. The terminals were connected to the first school through a leased telephone line, and additional equipment was required in order to operate the sharing arrangement. Table 4 shows the additional costs incurred for a shared A-16 system. With the shared arrangement, two classrooms must be utilized for the terminals rather than one classroom. Based upon the costs for a classroom and required renovations that were presented in Table 2 and replicated in Table 4, the total cost of additional facilities for the shared arrangement would be $68,500, which would be about $8,524 on an annualized basis.

The additional equipment (two modems and two multiplexers) and their installation have a cost of almost $12,500, which translates into an annualized cost of about $2,866. Taken together the additional outlay for the shared facilities and equipment is almost $81,000, which translates into an annualized cost (using a 10 percent interest rate on the undepreciated portion) of $11,390. With respect to personnel for the shared arrangement, we assume that the administrative costs for making financial arrangements and monitoring contracts is roughly equivalent to the single-school approach. However, an additional coordinator is needed for the classroom in the shared configuration, and additional provision for substitutes is necessary.

TABLE 4. ADDITIONAL COSTS INCURRED FOR SHARED A-16 SYSTEM, 1977-1978.

Cost Categories	*Amortization Period (years)*	*Cost*		*Annualized Cost 10%*	
Facility					
Construction of a CAI room	25	$ 50,000		$ 5,508	
Renovation	10	18,500		3,016	
Subtotal			$ 68,500		$ 8,524
Equipment					
Two modems	6	$ 4,710		$	
Two multiplexers	6	7,550			
Installation	6	200			
		12,460		2,866	
Total			$ 80,960		$ 11,390
Personnel					
One coordinator				22,500	
Fringe benefits on above at 16.7%				3,758	
Substitutes				390	
Subtotal					$ 26,648
Maintenance					
Printer				$ 360	
Miscellaneous				$ 3,000	
Grand Total			$ 80,960		$ 41,398

Note: It is assumed that the system is shared by two schools in the same local telephone area. If schools are at a greater distance, the miscellaneous cost category will increase according to the increase in telephone charges.

These are estimated to cost about $26,648 per year. The training cost for the additional coordinator is so small that it is inconsequential (about $150 for the 1.5 day of salary) and will not be included in the total.

Additional costs of maintenance seem to affect only the additional printer at $360 a year; the modems and multiplexers are maintained on the basic CCC contract so their costs cannot be easily broken out. Miscellaneous costs include the telephone line between schools, routine maintenance of the facilities, lighting, heating, electric power, and supplies. These are estimated at about $3,000 per year, and insurance costs are not affected by distributing the terminals between the two schools.

When these additional costs of the shared arrangements are totaled, about $41,400 is added to the total cost in comparison with the single-classroom, 32-terminal A-16 approach. Again, assuming 23 daily sessions per terminal and a total cost of about $141,000 per year for the shared system, the annual cost per daily session of CAI instruction is about $192. In other words, the shared system increases the cost per session by about 40 percent or $56.

COST FEASIBILITY

Are these costs high or low? That depends on what the costs are buying in terms of educational services and effectiveness in relation to what spending those funds on alternatives might produce. Such cost effectiveness comparisons are absolutely essential in using cost information to ascertain whether a particular educational technology or other instructional approach is a good investment. However, we lack both the cost of other alternatives and effectiveness data on CAI versus other alternatives for this study. Some of those data will be forthcoming at the completion of the CAI experiment and can be drawn upon for cost effectiveness comparisons at that time.

The purpose of cost feasibility analysis is much more modest. It simply asks if the costs of the instructional approach can be accommodated within the limits of the budget assigned for such purposes. In order to answer that question, we will compare the costs of CAI with the level of funding provided for compensatory education by Title I of the Elementary and Secondary Education Act of 1965. That is, presumably the CAI system that is being evaluated is addressed primarily to drill and practice for remediation.

In fiscal year 1977, Title I had appropriations of about $2 billion for about 5 million youngsters. This means that on the average about

$400 was provided for each of the students covered by the program. But not all of this amount was allocated to classroom instruction. Some was expended on such items as administration, health, diagnostic, and nutrition services. However, let us assume that about $400 per pupil represents an upper limit for compensatory education in the classroom. Using this as a basis for cost feasibility, $400 would cover about three daily sessions of CAI at $136 per session with 32 terminals to a classroom, or two sessions at $192 under the shared arrangement. This means that all three curricula could be provided under the lower cost configuration, or two could be provided under the higher cost one. It also means that two curricula, for example reading and mathematics, could be provided under the lower cost option, while allowing the remaining $128 per student to be used for other purposes. On this basis, one would conclude that the CAI approach that has been evaluated meets a general cost feasibility test. That is, it is feasible to consider this approach within the constraints of existing provisions for compensatory education.

COSTS OF A MORE ADVANCED SYSTEM

One of the major questions that arises in evaluating the costs of a changing technology is the direction and magnitude of future costs based upon more advanced approaches. This is particularly important in any strategy based upon computers because the technology of minicomputers and memory devices has been developing at a rapid pace with drastic reductions in the cost of any given capability. The longer run situation would thus suggest that at least the cost of equipment at a given performance level would decline, and it is important to ascertain the impact of these potential equipment cost declines on the overall costs of CAI.

However, before examining some evidence on this question, it is important to point out a phenomenon that is typically overlooked in predicting cost changes of technological innovation. The annualized costs of all computer equipment, including the terminals, represented only about 28 percent of total annualized costs, as evidenced by comparing the costs of $27,873 in Table 2 with the total costs of $100,000 for a 32-terminal classroom. This means that even a rather drastic reduction in the 28 percent of the cost accounted for by equipment will amount to a much smaller reduction in the total cost. For example, if the cost of equipment declined by one-third, total costs would decline by less than 10 percent. At the same time, the costs of personnel, maintenance, construction, and other personnel

intensive categories are rising rapidly, at least partially offsetting the potential declines in the cost of computer hardware. Accordingly, it is important to recognize that there will be inherent limits to cost reduction for CAI, even with rapid technological improvements in hardware.

In the particular case of the A-16 system, we were fortunate in that CCC had developed a more advanced CAI approach during the implementation phase of the ETS/LAUSD experiment. The more advanced computer is the CCC-17, which can drive about 96 terminals rather than the 32 terminals to which the A-16 is limited. CCC also claims that the 17 is more flexible and productive than the A-16 for a number of reasons. First, it uses special terminals provided by CCC that permit more flexible design and format of curricula as well as a wider variety of interactive feedback responses between the pupil and the computer. Second, the central processing unit has greater capacity for storing additional curricula and can process curricula of a wider variety than the A-16. For these reasons the CCC-17 may also be more effective for each session than the A-16, although that is ultimately an empirical issue rather than a theoretical one. CCC has provided the CCC-17 for one classroom for the final year of the ETS/LAUSD experiment, hence some empirical data should be forthcoming on this issue.

However, the purpose of this investigation is to ascertain the cost per session of the newer technology. Because the CCC-17 represents a larger system capable of supporting 96 terminals, we will estimate the costs of using a single CCC-17 for providing CAI to three classrooms of 32 terminals. This will enable us ultimately to compare the costs of the CCC-17 for 96 terminals with that of the A-16 on a 32-terminal classroom basis.

Table 5 shows the estimated total and annualized costs of both the facilities and equipment for the CCC-17 configuration. The cost of the facilities component is identical to that shown in Table 2 except that it is based upon three classrooms rather than one classroom. (Of course we will evaluate the costs per session based upon the larger number of terminals serviced by the CCC-17 to make the cost estimates comparable on a student session basis.) The equipment costs include the CCC-17 system, 96 terminals, a cluster controller for every 32 terminals that provides power to the terminals and that routes information between the computer and terminals, a printer for each school, modems for remote schools, and tables for each CAI room. All cost figures are taken from published documents furnished by the marketing office of CCC and dated April 17, 1978. Total facilities and equipment costs are $534,114 or about $101,128 in

TABLE 5. ANNUALIZED COST FOR THREE SCHOOLS SHARING THE CCC-17 SYSTEM, 1977-1978.

Cost Categories	*Amortization Period (years)*	*Cost*		*Annualized Cost* 0%	10%	15%
Facilities						
Construction of CAI room	25	$150,000		$ 6,000	$ 16,500	$ 23,250
Renovations	10	55,000		5,550	9,047	11,045
Subtotal			$205,500	$ 11,550	$ 25,547	$ 34,295
Equipment						
Computer-related equipment (includes terminals)	6	$314,814				
Installation	6	13,800				
Subtotal			$328,614	$ 54,769	$ 75,581	$ 86,754
Total facilities and equipment			$534,114	$ 66,319	$101,128	$121,049

TABLE 6. ANNUAL COSTS OF PERSONNEL, TRAINING, CURRICULUM RENTAL, MAINTENANCE, AND MISCELLANEOUS COMPONENTS OF THE CCC-17.

Personnel		
Administration	$ 5,895	
Coordinators	67,500	
Fringe benefits on above at 16.7%	12,257	
TAs	15,660	
Substitutes	2,340	
Subtotal		$103,652
Training (indirect costs)		$ 1,350
Curriculum rental		20,857
Maintenance		42,072
Miscellaneous		18,000
Total		$185,931

annualized costs when the interest rate on the undepreciated investment is 10 percent.

Personnel costs and the indirect costs of training were calculated in the same manner for the CCC-17 configuration as for the A-16 except that they are shown for three classrooms. These and other costs are reflected in Table 6. Curriculum rental was estimated by CCC at $20,857 and maintenance at $42,072. The miscellaneous costs are also similar to those calculated for the A-16. The total of all of these components is $181,931 and when the annualized costs of the equipment and facilities of $101,128 are added, the total annualized cost of the CCC-17 in 1977-1978 was estimated to be $287,059. In order to find the average cost per session, we need only divide this annual cost by the number of daily sessions provided on an annual basis. This is shown under different assumptions about the number of daily sessions provided:

Number of Sessions per Day		*Annual Cost per Daily Session*
Per Terminal	*Per 96 Terminals*	
21	2,016	$142.30
23	2,208	130.00
25	2,400	119.60

Based upon the median number of 23 daily sessions, the average cost per session for the CCC-17 is estimated to be about $130 in comparison with about $136 for the A-16.[9]

This suggests that the CCC-17 has a cost that is about 5 percent lower per CAI session than the A-16. This represents a rather small difference, especially because it assumes that the CCC-17 is utilized to capacity. One of the advantages of the smaller scale of the A-16 is that it provides somewhat more flexibility. Because it can be utilized in multiples of 32 terminals, there is likely to be less of a problem in underutilization than a system that must be implemented in multiples of 96 terminals. Because of the high fixed costs of these types of systems, underutilization hardly reduces total costs at all. This means that one must divide relatively irreducible total costs over fewer sessions, with a marked rise in cost per session. For that reason, the 5 percent reduction in cost per session under assumptions of full utilization would deteriorate rather quickly if the CCC-17 could not be fully utilized at a scale of 96 terminals.

One other point that ought to be emphasized is that of the total annual cost of $287,000 for the CCC-17, only about $76,000 is accounted for by the cost of the computer hardware. This means that almost three-quarters of the cost is allocable to factors that are not ostensibly affected by improvements in computer technology, thus limiting the cost savings obtainable by technological advances in the CAI system. In fact, as a general rule, virtually all technologically based instructional systems will show that only about one-quarter to one-third of the costs are associated with their hardware. This means that drastic reductions in the costs of such hardware may have only nominal effects on overall costs of the instructional strategy. Further, to the degree that the decrease in even those costs is associated with a larger scale of operation, even these cost reductions may not be realized unless the system can be utilized to full capacity.

It should be noted that according to CCC, the CCC-17 is educationally superior to the A-16. Admittedly the cost per session is not as important as the cost per unit of educational effectiveness. Thus, even if the costs of the CCC-17 are comparable to those of

9. Jamison et al. (1970) suggest that at that time a cost of $50 per session was attainable on an earlier CCC system. That estimate seems overly optimistic; even when adjusted for inflation it is about half of our estimates. Most of the difference appears to arise from the fact that coordinators were not used in the configuration that they describe as well as the assumption that the utilization rate would be 25 sessions daily. They do not mention the number of minutes per session. Early "drill and practice" curricula utilized 7-minute sessions, and they may be assuming these shorter sessions.

the A-16, a superior level of effectiveness may still make it a better investment. However, without data on the relative effectiveness of the two systems, it is impossible to evaluate this claim.

SUMMARY

The purpose of this paper was to estimate both costs and cost feasibility of utilizing a particular CAI approach for compensatory educational purposes. The particular approach that was chosen is the CCC A-16 and its implementation for a four-year experiment on the effectiveness of CAI that had been established in the Los Angeles Unified School District. Based upon the ingredients approach to cost analysis, it was found that up to three sessions of drill and practice of 10 minutes duration could be provided for each disadvantaged child at the 1977-1978 level of Title I expenditures. This means that three different subjects could be provided, or that multiple sessions in one or two subjects could be offered, for each child. As such, it appears that the instructional strategy is cost feasible within present provisions for compensatory education. Utilizing the A-16 between two schools would increase costs rather substantially, but two sessions of CAI would still be feasible within 1977-1978 compensatory educational allocations.

Costs were also estimated for the more advanced CCC-17 computer system, and somewhat surprisingly the costs were in the same range as those of the A-16. In part, this finding reflects the very heavy software component of CAI approaches, and, in part, it may reflect the possibility that the CCC-17 is more effective than the A-16 (even though the costs are quite similar). It is clear that a more exhaustive analysis of the merits of different CAI approaches, as well as a comparison between them and other instructional strategies, will require effectiveness data as well as cost estimates. Some of these should be forthcoming from the ETS/LAUSD experiment, and it is hoped that a cost effectiveness comparison can be made at some future date.

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