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ABSTRACT

The purpose of this paper is to examine what is known about the costs and cost-effectiveness of computer-assisted instruction (CAI) by presenting an appropriate cost methodology, applying it to CAI, and exploring the validity of four popular assumptions. These assumptions are: (1) that computer hardware accounts for most of the cost of delivering CAI; (2) that drastic declines in future costs of computers will create similar reductions in CAI; (3) that networks of microcomputers used for CAI are less costly than minicomputers with similar capabilities; and (4) that CAI has been found to be more cost effective than other instructional alternatives. The first three assumptions are directly contradicted by the available evidence. With respect to cost-effectiveness in raising student achievement in mathematics and reading, CAI was found to be more cost-effective than reducing class size, increasing the length of the school day, or adult tutoring, but considerably less cost-effective than peer tutoring. A bibliography of 11 citations is appended. (Author/MLF)

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SCHOOL OF EDUCATION STANFORD UNIVERSITY

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Abstract

The purpose of this paper is to examine what is known about the costs and cost-effectiveness of computer-assisted instruction (CAI) by presenting an appropriate cost methodology, applying it to CAI, and exploring the validity of four popular assumptions. These assumptions are: (1) that computer hardware accounts for most of the cost of delivering CAI; (2) that drastic declines in future costs of computers will create similar cost reductions in CAI; (3) that networks of micro-computers used for CAI are less costly than mini-computers with similar capabilities; and (4) that CAI has been found to be more cost-effective than other instructional alternatives. The first three assumptions are directly contradicted by the available evidence. With respect to cost-effectiveness in raising student achievement in mathematics and reading, CAI was found to be more cost-effective than reducing class size, increasing the length of the school day, and adult tutoring, but considerably less effective than peer tutoring.

I- INTRODUCTION

Computer-assisted instruction (CAI) has been used in American elementary and secondary schools for two decades. Early applications of computers to education were based upon the use of a central main-frame computer linked to many schools over a large geographic area through telephone lines or mini-computers in which a central processing unit was connected to student terminals in a school or school district (Alpert and Bitzer 1970; Suppes and Morningstar 1969). However, the recent interest in CAI has stemmed mainly from the introduction of micro-computers into the schools.

Micro-computers allow a higher degree of flexibility in deployment and use, and do not require the elaborate communications networks associated with mainframe and mini-computers. A school can obtain a single micro-computer or multiple micro-computers. They can be placed in individual classrooms, a resource center, or computer laboratories, and they can be used as individual stations with highly diverse applications or for common instructional tasks. Although they can be linked to each other in local area networks, they can be used independently with no interconnections whatsoever.

Since about 1978, the compelling case for micro-computers in instruction stems not only from their flexibility, but from reductions in cost and increases in performance. Between 1978 and 1984, the cost for a given level of performance declined by 50 percent or more. This decline in cost accompanied by the emerging centrality of computers in the workplace has accelerated the purchase of micro-computers by schools and the integration of CAI into the school curriculum. By January of 1983 some 53 percent of all American schools and 85 percent of high schools had at least one computer according to a major national survey (Center for Social Organization of Schools 1983 a: 2), and the penetration of the micro-computer is certainly considerably higher today.

The purpose of this study is to look more closely at the issue of cost and cost-effectiveness of the use of micro-computers for CAI. There are four popular assumptions on this subject which serve as a useful point of departure. These assumptions are: (1) that computer hardware accounts for most of the cost of delivering CAI; (2) that drastic declines in future costs of computers will create similar cost reductions for CAI; (3) that networks of micro-computers used for CAI are less costly than mini-computers with the same capabilities; and (4) that CAI has been found to be more cost-effective than other instructional alternatives.

Each of these assumptions will be evaluated according to the evidence that is available. But, before such an assessment can be undertaken, it is important to define costs, present a method of measuring costs, evaluate specifically the cost components of CAI, and provide some cost estimates for CAI services. The next section addresses the costs of CAI.

II- ESTIMATING COSTS OF CAI

What is the cost of CAI? When educators, policy-makers, computer firms, and parents address the costs of CAI, they typically refer only to the costs of purchasing the micro-computers alone. Since a micro-computer with instructional capabilities costs less than $1000 and can last for several years, a school with 1000 students could acquire one micro-computer for every 20 students or 50 micro-computers for about $50,000. This would amount to the annual salaries of two teachers. But, since the computers would last for several years, the cost in a single year would be only a fraction of this. For example, if the machines were used for three years, the apparent cost would be only about $17,000 a year or $17 a student per year. Clearly such a cost seems very modest in comparison with the $3,000 or so spent annually on each student for all school services.

The problem with this type of calculation is that micro-computers in themselves are only one element in a more complex system for delivering instruction. In addition to the computers, schools need a secure facility to house them, curriculum software, knowledgeable personnel, provisions for maintenance, and other support services. The proper way to determine the cost of CAI is to ascertain what ingredients are needed to deliver a particular type and level of instructional services, to ascertain the cost of those ingredients, and to determine who pays for them. This approach is known as the resource or ingredients approach and represents a systematic and economically sound method for ascertaining costs (Levin 1983). In this context, we will use the words <u>ingredients</u> and <u>resources</u> interchangeably.

Before exploring the ingredients method and its application to CAI, it is useful to define what is meant by "cost" (Levin 1983: Chap. 3). Cost refers to the value of what is given up by using resources in one way rather than in their best alternative use. The use of resources for one endeavor means that some other use of those resources is sacrificed or lost. The ingredients method is based upon this definition by evaluating in monetary terms the total value of all resources used in the CAI intervention. It is a comprehensive approach to determining all of the ingredients required for the intervention, assessing and summarizing their costs, and apportioning those costs among different constituencies such as levels of government, parents, volunteers, and so on.

Identifying Ingredients

The first step in using the ingredients approach is to identify the ingredients that will be needed for a CAI intervention. These can generally be divided among personnel, facilities, equipment, materials and supplies, and all other. The personnel category includes virtually all of the human resources required including teaching specialists, coordinators, and administrators. Each position should be identified in terms of the proportion of a full-time position required as well as the qualifications of the person occupying the position. Facilities refer to the physical space required for the intervention. This may be a classroom or a portion of a classroom. The facility should be identified according to both the amount of space needed and its quality. For example, if security devices and air conditioning are required, these should be stipulated.

Equipment includes all of the hardware that will be required. In the case of a micro-computer intervention this will include the micro-computers, printers, and other devices required for the intervention. It may include such auxiliary equipment as cooling fans, anti-surge devices, and added peripheral equipment such as disk drives or cassette recorders. Materials and supplies include the curriculum soft- ware, instructional manuals, paper for the printers, and other requirements.

The "all other" or miscellaneous category should include the costs of energy (heating, lighting, and power), routine maintenance of the classroom, hardware maintenance, fire and theft insurance, and training. The hardware maintenance and insurance could alternatively be included in the equipment category rather than the miscellaneous one. If specific administrative positions cannot be identified for the personnel category, it may be useful to make some estimate of administrative overhead in this category to cover the purchasing, contracting, and other arrangements that will have to be made by the principal and the central office staff of the school district.

The guiding principle for listing the ingredients of the proposed CAI project is to be as complete as possible, especially for the major inputs. It is important to remember that one copy of software is not adequate for multiple micro-computers. In general, a copy must be purchased for all students who will use the software simultaneously or an agreement must be negotiated with the software manufacturer that permits the school to pay a fee to produce a specified number of copies for internal use. Although it may be tempting to buy a single copy and duplicate it, such an activity is illegal.

Valuing Ingredients

Once the ingredients that are required for the CAI intervention are stipulated, it is necessary to determine their cost. There is a standard methodology for doing this that is readily available (Levin 1983: Chap. 4), and space precludes our replicating these details. However, it is useful to indicate some of the principles for setting out the costs of ingredients. First, all ingredients are costed, even if they appear to be "free". The reason for this is that even contributed inputs such as the time of a volunteer or a donation are not free to the donor, even though they do not have a cost to the school or school district. In those cases, we wish to acknowledge the costs, even though at a later stage we will apportion them to other constituencies than the school and school district. This is not only desirable for purposes of completeness, but it is also important to recognize such costs in the event that donations of volunteer time and other resources are not obtainable so that they may make a claim on school resources at some future time.

Second, costs are set out at their market values for the same reason. Take the case of a classroom that is provided for a computer laboratory. At a budgetary level there appears to be no cost because there is no financial transaction. However, given our concept of "opportunity cost" for ingredients, there is always a cost as long as the resource has alternative uses. In the case of a classroom, that space could be used for other instructional purposes or for administrative functions, or it could be leased to outside users for day-care, senior citizen or commercial uses. In an age of declining enrollments many school districts have sold buildings or leased portions of school facilities that were unused. By using such "extra" space for CAI, the school district sacrifices what it could have obtained by leasing the facility. Accordingly, there is a cost to using a classroom for CAI as opposed to using it for other purposes, even though these costs will not be found on accounting statements.

Third, as suggested by these first two principles, budget or accounting statements do not include all of the costs of an intervention. Not only do they exclude resources for which there is no budgetary transaction such as the donated ones or employment of available space that has other competing uses, but they provide a misleading view of annual costs for any equipment purchases. The reason for this is that equipment such as micro-computers has an expected life of 3-6 years, depending upon its use and maintenance. However, conventional school accounting practices require that the entire amount be budgeted during the year of purchase so that the annual estimated costs in the first year are overestimated by including the complete cost of equipment in that year. In subsequent years the cost of CAI is underestimated because the cost of equipment is not reflected in the budget. Yet, consider that the costs should be spread over all of the years of use to get an accurate picture of the annual cost of CAI. Although this practice of apportioning costs over the lifetime of equipment is a standard one in cost accounting, it is not common in the construction of school budgets. Thus, one should not rely completely on school budgets if one wishes to obtain an accurate picture of annual costs of an intervention.

Finally, it is useful to state costs in annual terms. They can then be readily compared with the annual costs of other possible interventions as well as the overall annual costs of school operations. Accordingly, all of the analyses that follow will be based upon the estimate of annual costs, although we will also note the initial costs of acquiring micro-computers that will last a number of years.

Given this background, it is possible to suggest some principles for estimating the costs of each category. Costs are generally easiest to estimate for the personnel category. The reason for this is that any school district can ascertain readily what it needs to pay for most types of instructional personnel. These costs should include not only salaries, but fringe benefits as well. In the case of volunteers, the cost estimate should be based upon what it would cost the school or school district if paid staff had to be hired for such positions.

Facilities costs can be estinated in a number of ways. The easiest way is to ascertain the leased value of equivalent space. This can be done by specifying the amount of space and its characteristics and checking with a local real estate firm to determine what such space would cost in that location. A different method is to determine the replacement cost of the facility and to convert the replacement cost into an annual value based upon the lifetime of the facility and the interest rate that reflects the "opportunity cost" of using resources for capital investment (Levin 1983: 67-71).

The annual cost of equipment can be estimated in a similar manner. If one knows the purchase price and life of the equipment and the pertinent interest rate, one can use a simple table of "annualization factors" to determine the annual cost (Levin 1983: 70). Clearly, the greater the lifetime of the equipment, the lower the annual cost. In some cases it is desirable to include the insurance costs for fire and theft as well as maintenance costs of the equipment in the equipment category rather than in the miscellaneous one. Both of these are easily ascertainable because they are generally paid for on an annual basis (often a percentage of the value of the equipment).

The most important component of the materials and supplies category is likely to be the curriculum software. If it is leased for an annual fee, its annual cost is easily ascertained. If it is purchased, its annual cost can be derived in a similar fashion to that of the hardware, although it should be remembered that the software may have a different lifetime than the hardware. The annual cost of other materials and supplies can be estimated on the basis of the costs of the ingredients that are needed for this category.

Finally, the miscellaneous or other ingredients can be valued according to their particular characteristics. The costs of energy use and facilities maintenance can generally be estimated on the basis of school experience for these categories. Training will include not only the direct cost of instructors and materials, but also the reimbursement of salaries of trainees during the training sessions.

To the degree that the trainees are expected to stay for a number of years without requiring annual retraining, the initial costs of training can be "annualized" in a way similar to that of the equipment and the software.

In summary, a standard set of procedures can be used to estimate the costs of the ingredients required for CAI. Once these costs are estimated, they can be added to obtain the total costs for the intervention on an annual basis. They can also be divided into those that will be borne by the school or school district and by others, and they can be used to estimate the initial "out-of-pocket" costs that the school district will need to initiate the intervention.

Apportioning Costs

The ingredients method requires that all resources required for the intervention be stipulated and their costs be ascertained. This approach provides a complete picture of resource needs and their costs and can be used to determine the overall cost of the intervention. However, a school or school district will be concerned primarily with its share of the total costs. It is in the interest of the district to obtain as much outside assistance as possible in order to reduce its own costs. For example, it may be possible to get community volunteers to undertake some of the personnel responsibilities, particularly those of aides who will assist students in using the micro-computers. It is also common for computer firms to provide at least some equipment to schools at no cost. The State of California has passed legislation that provides tax credits to computer manufacturers for making such donations. Even in the absence of such legislation firms have incentives to give equipment to schools in order to get tax deductions and to prime both the school and home (parental) market for their products. Finally, some of the states provide subsidies to schools to promote computer instruction, and federal grants can be used to pay for all or some of the cost of CAI under the Education Consolidation and Improvement Act (ECIA).

After determining the full cost of the intervention when the value of all resources is accounted for, it is useful to divide the costs among those who bear them. In this way, it is possible to distinguish among costs that will be borne by the school district, other government agencies, volunteers, and private firms or other donors. This analysis also enables a determination of the types of support that the program will depr upon and the areas in which the school district will have to increase its share if the subsidies and donations do not materialize.

Initial Costs

A separate analysis can also be made of the initial or "up-front" costs. Such costs refer to those expenditures that must be made at the outset of the intervention, even though the acquisitions and improvements will last for several years and will not requir additional outlay. The best examples are the refurbishing of classrooms into computer laboratories and the acquisition of computers and software. In these cases, the usual practice is to pay for the improvements and equipment at the outset, even though good business practice would normally lead to financing them over their lifetimes. However, in the case of schools, only major capital construction is financed through borrowing. Refurbishing of buildings and acquisition of equipment are paid for immediately upon their completion or purchase. The ingredients method enables a separate accounting of any resources that must be paid for initially in order to calculate up-front costs. Of course, the leasing of computers and software as well as facilities (e.g. temporary classrooms) represents a way of reducing the initially high costs of financing this type of intervention.

Summary of Cost Analysis

In this section we have provided a brief summary of a method for ascertaining the costs of CAI. The main principles of the approach are the identification and stipulation of all ingredients—not just computer hardware; the costing of all ingredients according to their market value; the apportionment of costs among the various constituencies who will be expected to bear them; and the determination of what initial or up-front investment will be required by the school or school district to undertake the CAI program. In the next section, we will apply these principles to ascertaining the costs of CAI in order to evaluate some of the popular assumptions on the subject. These assumptions are: (1) that computer hardware accounts for most of the cost of CAI; (2) that drastic declines in computer costs will have a similar effect on the cost of CAI; (3) that networks of micro-computers are less costly than mini-computers with similar capabilities; and (4) that CAI has been found to be more cost-effective than other instructional alternatives. Each of these assumptions will be evaluated in turn on the basis of actual assessment of one of the most widespread applications of CAI.

III- ACTUAL COSTS OF CAI

The principles that were set out above have been used to estimate a major application of CAI in 1978 (Levin and Woo 1979) and in 1984 (Levin, Glass, and Meister 1984). However, before presenting these results, it is important to emphasize that they should be viewed as illustrative rather than definitive. The reason for this is that there are many different approaches to CAI, and there are many different settings. Each application may have different ingredient requirements and service levels as well as goals. In addition, costs for particular ingredients such as personnel may differ substantially among different settings. The advantage of the following examples is that they have been derived from one of the most widespread uses of CAI. In addition, they permit an examination of changes in cost levels and structure over time as well as a comparison of the costs of micro-computers and mini-computers for producing the same type and level of services.

The specific application of CAI that we will consider is that of "drill-and-practice." Drill-and-practice refers to the use of computer exercises to reinforce classroom instruction. It is the earliest application of computers to learning and has been used for at least two decades (Suppes and Morningstar 1969). A 1983 survey of schools found it to be the second most important computer application, occupying 23 percent of all student instructional time on computers at the elementary and secondary levels (Center for the Social Organization of Schools 1983 b: 7). Rigorous evaluations of computer drill-and-practice suggest that the intervention has strong positive effects on student achievement in mathematics and reading (Glass 1984; Ragosta, Holland, and Jamison 1982).

The most widely used and evaluated drill-and-practice approach is that of the Computer Curriculum Corporation (CCC). A prominent four-year evaluation of the CCC application was carried out in Los Angeles from 1976-1980, sponsored by the National Institute of Education and carried out by the Educational Testing Service (Ragosta, Holland, and Jamison 1982). In that intervention, elementary students were provided with ten-minute daily sessions of drill-and-practice in mathematics, reading, and language arts. Some students had more than one daily session, and the combinations of subjects to which students were assigned differed so that a child studying reading and language arts by computer could serve as a control for assessing the benefits of mathematics instruction for another child studying reading, language arts, and mathematics. Since the experiment ran for four years, it was also possible to make comparisons among students with up to four years of CAI and with different combinations of subjects as well as between students who had received CAI and those who had not.

The approach evaluated in the study requires a separate classroom with 32 terminals connected to a minicomputer. (A similar type of delivery system can be constructed using microcomputers that are arranged in a local network with a hard-disk storage device.) The minicomputer holds all computer curricula for all elementary grades and curriculum areas as well as student records on the number of sessions that students have taken and their progress. Since each terminal was used for about 23 sessions a day, the computer facility was able to accommodate a total of 736 sessions a day.

Personnel include a full-time coordinator and two part-time teaching aides as well as a small portion of administrative time. The CAI coordinator is responsible for the overall functioning of the CAI program including scheduling and coordination of instruction, reporting to teachers on student progress, and monitoring equipment functioning and maintenance. This role is serve by a classroom teacher who is trained in an intensive one and one-half day program. Teaching aides monitor the performance of students and assist them in understanding the CAI problems and solving them. In addition to the computer hardware and personnel, other inputs include a renovated classroom, curriculum rental, supplies, insurance, and maintenance.

TABLE I

Computer Assisted Instruction Ingredients and Costs
Minicomputer System

Number of Students: 736 (includes 23 sessions per terminal per day for 32 terminals).

Annual Cost	Ingredient
	PERSONNEL
$25,000	1 CAI Coordinator at $20,000 plus fringe benefits per year
6,000	2 teaching aides @ 600 hours at $5.00/hour
1,750	1 principal @ 5% time at $28,000 plus fringe benefits per year
	FACILITIES
5,775	Classroom for CAI laboratory (includes $1,000 for utilities and routine maintenance of the space)
3,010	Classroom renovation for CAI laboratory
244	Furnishings (includes teacher desk and chair and student chairs only)
	EQUIPMENT AND MATERIALS
4,982[a]	1 Microhost (CPU) with 1 Mb memory and 40 Mb storage at $21,700, annualized at 10% interest over 6 years[a]
4,857[a]	32 Computer Curriculum Corporation terminals at $21,152, annualized at 10% interest over 6 years[a]
207[a]	1 dot matrix (120 cps) printer at $900, annualized at 10% interest over 6 years[a]
11,434[a]	Software at $49,800, annualized at 10% interest over 6 years[a]
1,102[a]	Installation at $4,800, annualized at 10% interest over 6 years (includes CPT at $1,500, terminals at $3,200, and printer at $100)[a]

TABLE ONE (Continued)

Annual Cost	Ingredient
	EQUIPMENT AND MATERIALS (Continued)
6,400	Curriculum rental per year
3,000	Supplies
	OTHER
40	Training time for coordinator @ 1-1/2 days x $100/day, annualized at 10% interest over 5 years
855	Training time for 40 teachers @ 4 hours x $20.25/hour, annualized at 10% interest over 5 years
9,720	Maintenance (includes CPU at $3,600, terminals at $5,760, and printer at $360)
3,000	Insurance
$87,376	TOTAL COST PER YEAR
$ 119	COST PER STUDENT

[a]Costs quoted by Computer Curriculum Corporation as of 3/16/84.

Table One provides a summary of the ingredients and costs of the CAI system for a 32 terminal laboratory. Details for the cost analysis are found in Levin, Glass, and Meister (1984). The overall cost is about $87,000 per year or about $119 per year for a ten minute daily session. Hardware and software costs are based upon data for the Spring of 1984, while all other cost data are for 1980. Thus, overall costs would be somewhat higher in 1984 for the latter category. What is most instructive is the breakdown in costs among categories. The annualized cost of hardware (cost per year) accounts for only about 11 percent of the total cost, while personnel costs account for about 38 percent. Curriculum and other software costs represent 21 percent of the total, and hardware maintenance about 11 percent.

<u>How Dominant is the Cost of the Computer?</u>

This cost breakdown enables us to address the first popular assumption, namely that the cost of computer hardware dominates the cost of CAI. In this example, the cost of computer hardware represented only about one-ninth of the overall annual cost of providing CAI services. It is also important to note that although personnel accounted for about two-fifths of costs or over three times that of the computer hardware, staffing was relatively modest for such a busy facility with over 700 student sessions a day. The only personnel were a full-time coordinator ($20,000 a year plus fringe benefits), two part-time teaching aides (600 hours each @ $5.00 hour for a total of $6,000 a year) and a small amount of administrator time. It is reasonable to believe that this is probably a minimal staffing pattern for a facility with 32 terminals or 32 micro-computers that are fully utilized for the entire school day. It should be noted that several years of experience suggest that full utilization meant about 23 ten-minute sessions a day or the equivalent of four hours of continuous use over a six-hour school day. The remaining time was accounted for by time required for maintenance and testing of equipment, production of student records, lost time because of inoperative equipment, and time required during the transition from one student group to another.

Nor can one argue that this cost pattern is unique to a mini-computer with terminals in contrast to micro-computers. A similar micro-computer configuration is likely to be faced with similar staffing needs. Further, maintenance and software needs are not likely to be substantially different between mini-computers and micro-computers with the same service capacity. Indeed, in a later comparison of the costs of mini- and micro-computers, we will suggest that as of 1984 costs are roughly comparable or even favor the mini-computer over micro-computer networks with communication capabilities.

In large measure an understanding of all costs of CAI explains why school districts are unable to utilize efficiently the micro-computers that they purchase without making explicit logistical and cost provisions for other requirements. The purchase of micro-computers is a necessary condition--but not a sufficient one--for providing CAI services. For every dollar spent on such hardware some four or more dollars of other resources will be needed for the other resources required to provide instructional services such as supporting software, maintenance, personnel, and special facilities. The overall message is that although computer hardware may be the most visible component of a CAI delivery system, it accounts for a relatively small portion of the total costs of CAI. This is a lesson that is important for schools to learn if they are to provide CAI services rather than to lim[illegible] iemselves to the purchase of computers with the hope that the services will be produced automatically from the hardware.

Will the Costs of CAI Fall Drastically?

A second popular assumption is that the costs of providing CAI services will decline drastically with concomitant declines in the costs of mini- or micro-computers. This proposition can be examined both historically and logically. As part of the evaluation of the Los Angeles experiment, a cost analysis was undertaken in 1978 (Levin and Woo 1979). The overall cost of delivering 736 daily CAI sessions per year was estimated to be about $100,000 for the 1977-78 school year. The cost per year for a daily CAI session was estimated at $136 per student. Recall that the estimated cost of providing the same services in 1984 was about $119 per year for each student for a daily CAI session. Accordingly, even with substantial declines in the cost of the computer hardware between 1978 and 1984, the cost of providing CAI instruction had declined by only about 12.5 percent.

Let us examine this paradox more carefully. In 1978 the annual cost of computer hardware was estimated to be about 28 percent of the total annual cost of providing the CAI. We can ask what would happen to such costs if the hardware costs had declined by 50 percent. The answer is that there would have been a 14 percent reduction in the overall costs of service delivery, or half of 28 percent. According to the 1984 estimates, the actual share of hardware costs had declined to only 11 percent of total costs. This reduction in the proportion of costs attributible to hardware was due not only to a decline in hardware costs per se, but also to relative rises in the costs of some of the other ingredients.

Now, let us do a bold hypothetical exercise in arithmetic by assuming that hardware costs decline so drastically in future years that computers will be given away at no cost whatsoever. Although this is an absurd assumption, it is useful for seeing the limit to which a reduction in hardware costs can diminish the overall costs of CAI. Clearly, the use of free computers would reduce the cost of CAI services by only 11 percent in this example, as long as need for the other ingredients and their costs remained constant. Of course, to the degree that the cost of other ingredients such as those of personnel increase over time, not all of the cost reduction from free computers will be reflected in reduced costs of CAI services. In that case the cost decline would be less than 11 percent.

The popular assumption that the costs of CAI will decline drastically with reductions in hardware costs is inconsistent with basic arithmetic. It is only if improvements in hardware reduce the need or the cost of other ingredients that such an outcome would take place. Yet, it is difficult to see how a high level of computer utilization could be integrated into school curricula without at least minimal coordination and staffing, investment in software, adequate facilities, and so on. Neither the recent history nor the structure of CAI costs supports the view that there will be drastic declines in the costs of CAI services. It is only when CAI services are defined as the mere availability of computers that the view makes sense. As noted above, however, such a definition is naive and educationally indefensible.

Are Micro-Computers Cheaper Than Mini-Computers

The remarkable upsurge in popularity of micro-computers and their amazing flexibility and performance have contributed to the popular assumption that CAI is synonymous with the micro-computer. Micro-computers can be purchased and used singly, in small numbers, or in larger numbers when configured into a computer laboratory. Each micro-computer can be used independently or linked to other micro-computers in a local area network (Piele 1984). Schools have often initiated their CAI services by getting small numbers of micro-computers that are first used for instruction by a few teachers who are computer buffs (Meister 1984). Later, these enthusiasts may train other teachers, creating additional demands for micro-computers and placement of micro-computers in all or most classrooms or in a computer laboratory.

A major advantage of the micro-computer is the flexibility that it permits in accommodating a variety of different patterns of adoption and utilization. No major investment needs to be made initially as schools acquire equipment and software in small amounts for the purposes of familiarising staff and exploring the potential of CAI. Only later as CAI is introduced systematically into the curriculum do the commitments and costs rise.

But, there is one set of conditions under which this strategy may be counterproductive and even more costly than the use of a mini-computer with student terminals. This situation emerges as additional micro-computers are acquired, it often becomes desirable to link them into a local area network so that software, printers, disk drives, and data bases can be easily shared and communication is possible from one user to another. For example, in such a network a teacher could monitor the progress of individual students and offer suggestions to students in an unobtrusive manner by sending messages between the two micro-computers.

Once a school reaches the stage where it wishes to link its micro-computers into a network, however, it is addressing a task which is a basic function of a mini-computer with terminals. A mini-computer is a larger computer than a micro, and it is accessed by terminals. The terminals have keyboards and video-monitors, but no independent storage or processing capability. Rather that ability is contained in the central processing unit of the mini-computer. Since all terminals are linked to the central processing unit, sharing of software, peripheral equipment such as printers and storage devices, and communication among terminals are intrinsic to the mini-computer. Further, the same revolution in electronics that has reduced the cost and raised the capabilities of micro-computers has also had the same effects on mini-computers.

Accordingly, a cost comparison was made of a popular, local area network composed of micro-computers (Apple II's with a Corvus Omninet) and the mini-computer configuration used in the previous cost analyses. The comparison was limited to the hardware costs for delivering a similar set of curricula (Levin, Glass, and Meister 1984: 23-25). The costs of the two systems were found to be comparable, with the mini-computer slightly less costly per student. However, experience with micro-computer networks in schools have shown them to be less reliable at the present time than mini-computers, and their personnel requirements seem to be greater because of their complexity of operation. These suggest that on balance the higher reliability and lesser personnel needs attached to the mini-computer make it less costly than a comparable micro-computer network. It also suggests that if schools intend to plan for a local area network at the outset--rather than after acquiring micros--they should consider the mini-computer alternative.

IV- COST-EFFECTIVENESS OF CAI

A final popular belief that we wish to address is the view that the decline in cost of computers and rise in their capabilities as well as the explosion in availability of educational software have made CAI a more cost-effective alternative to instruction than traditional approaches. While this may be the case, rarely is evidence used to back up the claim. Cost-effectiveness studies require that systematic analyses of costs be available for addressing the same educational outcomes (Levin 1983). The relative lack of data on both costs and effects suggests that a high priority be attached to rigorous studies of the cost-effectiveness of CAI.

Recent research undertaken at the Institute for Research on Educational Finance and Governance (IFG) attempted to compare the cost-effectiveness of drill-and-practice CAI with that of three other alternatives for increasing student achievement in mathematics and reading in elementary schools (Levin, Glass, and Meister 1984). The other interventions that were considered in the analysis were reducing class size, increasing instructional time, and cross-age tutoring. Both CAI and increasing instructional time have been featured prominently among the recommendations of the national reports on educational reform, while reducing class size and cross-age tutoring represent more traditional approaches. The emphasis in selecting interventions specific forms of the interventions was to choose those that were replicable in elementary schools (as opposed to those developed for experimental purposes), that had reasonable evaluation data from which we could estimate effectiveness, and that had sufficient detail to facilitate identification of ingredients and their costs.

The specific CAI intervention that was evaluated is based upon the CCC drill-and-practice curriculum that was described previously. The intervention for increasing instructional time entailed the addition of one hour of instruction per day, half of it devoted to mathematics, and half devoted to reading. The main ingredient for costing purposes was additional teacher time. Cross-age tutoring refers to a peer component, the tutoring of younger students by older ones under the supervision of adults for grades 2 and 3 and an adult component comprised of adult tutoring of students in grades 5 and 6. The specific tutoring program chosen for this study was the Cross-Age Structured Tutoring Program for Reading and Mathematics in the Boise (Idaho) Schools. Staffing for each elementary school of about 300 to 400 students includes a tutor manager in reading, a tutor manager in mathematics, and an adult tutor for each subject. Daily tutoring sessions last about 20 minutes a day using a commercially available curriculum. The reduction of class size was based upon examining the costs and effects of reducing class size incrementally from 35 to 30 students; 30 to 25 students; 25 to 20 students; and 35 to 20 students. Costs of this intervention are associated with the additional classrooms and teachers that are required.

Effectiveness

The effectiveness of each of the interventions was estimated by doing a two stage analysis, and details can be found in Glass (1984). First the available evaluations for each class of intervention were assessed to obtain a range of their effects on student achievement. Second, evaluations of the specific interventions for CAI, increasing instructional time, and cross-age tutoring were assessed to obtain specific estimates of achievement effects. The effects of reductions in class size were derived from a meta-analysis of about 80 evaluations on the subject.The results of the first and second stage were compared to assure that the specific interventions were representative of those of the classes of interventions chosen.

TABLE TWO

Estimated Effectiveness of Four Educational Interventions in Months of Additional Student Gain Per Year of Instruction

		Mathematics	Reading
CAI		1.2	2.3
Cross-Age Tutoring			
Peer Component		9.7	4.8
Adult Component		6.7	3.8
Increasing Instructional Time		0.3	0.7
Reducing Class Size			
From	To		
35	30	0.6	0.3
30	25	0.7	0.4
25	20	0.9	0.5
35	20	2.2	1.1

Table Two shows the estimated effectiveness of each of the interventions. Since the interventions represent supplements to existing instruction, the effects are evaluated in terms of the additional achievement expected for children receiving each intervention relative to similar students who are not exposed to it. Effect sizes were estimated in terms of achievement gains in standard deviation units. However, a standard deviation at the elementary level is approximately equal to a year of achievement, where an academic year is equal to 10 months. Accordingly, we have converted the achievement results into months of student gain per year of instruction to provide a more familiar measure of achievement. Table Two shows the expected monthly gains in achievement of students for each intervention, where each month of gain is about one-tenth of a school year of achievement.

The CAI intervention produced a healthy result with over a month of student gain in mathematics and over two months, almost a quarter of a year, in reading for a ten-minute daily session in each subject over the school year. However, even larger effects were found for both the peer and adult components of cross-age tutoring. Peer tutoring produced gains of almost a full year in mathematics achievement and half a year in reading achievement, and gains from adult tutoring were almost as impressive. In contrast, reductions in class size showed less than a month of gain in both mathematics and reading for each five-student decrement. The direct reduction from 35 to 20 students, however, was associated with gains similar to CAI, but with greater achievement gains in mathematics than reading. Finally, the effectiveness of an additional half hour a day of instruction in each subject showed very small gains.

TABLE THREE

Annual Cost Per Student Per Subject of Four Educational Interventions

			Cost per Student per Subject
CAI			$119
Cross-Age Tutoring			
Peer Component			$212
Adult Component			$827
Increasing Instructional Time			$ 61
Reducing Class Size			
	From	To	
	35	30	$ 45
	30	25	$ 63
	25	20	$ 94
	35	20	$201

Table Three shows the annual costs per student of each intervention. The annual cost per student per subject represents the total value of resources required to replicate each intervention, divided by the number of students receiving the instructional benefits, where the ingredients method was used to estimate costs. The most costly of the interventions was adult tutoring, followed by peer tutoring and a reduction in class size from 35 to 20. The cost of CAI was about half that of peer tutoring. Reductions in class size by five student decrements and increasing instructional time by one half hour a day in each subject were the least costly interventions.

TABLE FOUR

Estimated Effectiveness of Four Educational Interventions in Months of Additional Student Achievement Gain Per Year of Instruction for Each $100 Cost Per Student

			Mathematics	Reading
CAI			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

When costs for each intervention in Table Three are combined with the effectiveness results from Table Two, cost-effectiveness ratios are obtained. With these it is possible to ascertain the expected gains in student achievement associated with a given cost. Table Four shows the gains in student achievement from each intervention for each $100 cost per pupil. The CAI intervention is estimated to produce a gain of about one month in mathematics and two months in reading for each $100 in cost per student. In contrast, peer tutoring is associated with almost half a year of achievement gain in mathematics and almost a quarter year in reading. Other interventions tend to show lower cost-effectiveness than either peer tutoring or CAI. Indeed, even though adult tutoring showed one of the highest effects, its high cost creates a cost-effectiveness ratio that is among the lowest of the four interventions.

Based upon these results, it appears that the specific CAI intervention evaluated in this study was more cost-effective than adult tutoring, reducing class size, or increasing instructional time. However, it was considerably less cost-effective than peer tutoring in mathematics and slightly less cost-effective in reading. This suggests that the CAI intervention does perform comparatively well according to cost-effectiveness criteria, although it is not necessarily the most cost-effective approach to improving mathematics and reading achievement in the elementary grades. Although these results are based upon CAI delivery with mini-computers rather than micro-computers, analysis of micro-computers for this specific CAI intervention suggests that they would be more costly (Levin, Glass, and Meister 1984: 23-25 and Appendix Tables A-6.1 and A-6.2.) and would be associated with lower rather than higher cost-effectiveness ratios.

Of course, as new developments occur in CAI curricula and their applications, CAI might improve its relative cost-effectiveness. Evidence at the present time suggests, however, that educators should not assume blindly that CAI is a more cost-effective intervention than other alternatives. Clearly, the overall choice must depend upon a school's instructional goals, available resources for reaching those goals, proficiency in using computers, and many other factors.

The over-riding theme of this paper is that popular assumptions about costs and cost-effectiveness of CAI are often not supported by evidence. To the degree that decisions to adopt CAI are made on the basis of such assumptions, they may be costly and inefficient. It is crucial that systematic evaluation of CAI proceed as rapidly as the proliferation of computers in instruction in order to ascertain the most promising applications in a framework which considers both their educational effectiveness and their costs.

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