The Costs of Computers in Classrooms:
Data from Developing Countries

Marianne Bakia, mbakia@fas.org

Estimating the Costs of Computer Projects

Total Cost of Ownership (TCO) is a concept used among American businesses today to estimate what a computer is likely to cost over the life of the investment. It has also been applied to technology projects in education, although rarely to the unique set of circumstances facing developing countries. In the cost tables presented here, expenditures in four countries, Barbados, Turkey, Chile, and Egypt, are cited most often because it was for these countries that the most detailed information was available. The first two countries, Barbados and Turkey, are grouped together because the percentages are of total project costs. The estimates were developed from the perspective of the central ministry. Estimates in the second two countries, Chile and Egypt, are from the perspective of individual schools, and so do not include centralized costs. The analysis for these two countries therefore excludes central management and planning or monitoring and evaluation. When percentages are included, they are of these school-based costs, not total project costs. All estimates, unless otherwise specified, assume that the majority of computers are grouped in a single "laboratory" or classroom.

Overview of Total Costs

The projects presented here had compatible objectives; all addressed issues related to computer use as an instrument of curricular reform. In most cases, computer technology was introduced for some combination of three purposes: to increase technology skills, to reform pedagogy and curriculum, and to increase access to resources and information. Despite these common objectives, the projects varied considerably in scope and scale, and as a result, in total and unit costs. **Table 1** summarizes the allocation of costs by category as well as reports total costs per school, per student, and per computer.

One of the interesting facts that emerged from this analysis is that over time, countries appear to be purchasing computers in the $1,000 - $2,000 price range, despite decreases in computer prices, holding computer power constant. Further, annual costs per computer also hovered in the $1,000 – 2,000 range, suggesting that initial hardware costs represent only a

Table 1: Summary of Cost by Project[1]

	National Estimates		School-based Estimates	
Cost Category	Barbados (1998)	Turkey (1999)	Chile (1995)	Egypt (1998)
Central Management (planning and recurrent)	11%	2%	N/A	N/A
Hardware (annualized investment per school)	33% ($150,000)	31% ($ 6,800)	49% ($ 5,540)	24% ($ 10,950)
Software (annualized investment per school)	13% ($ 56,000)	6% ($ 1,240)	2% ($ 171)	2% ($ 749)
Facilities and Renovation (annualized investment per school)	19% ($ 85,000)	5% ($ 985)	3% ($ 350)	7% ($ 3,100)
Connectivity (recurrent)	10% ($ 85,000)	5% ($ 960)	10% ($ 1,165)	6% ($ 3,000)
Maintenance and Tech Sup (recurrent including personnel)	18%	42%	N/A	4%
Professional Development (annualized investment and recurrent)	4% ($ 18,430)	2% ($ 535)	13% ($ 1,445)	29% ($ 13,275)
Total Annual Cost	$30,279,100	$54,206,336	N/A	N/A
Total Annual Cost Per School	$ 451,930	$ 21,685	$ 11,215	$ 45,045
Total Annual Cost Per Student	$ 646	$ 32	$ 56	$ 75
Total Annual Cost Per Computer	$ 1,938	$ 1,280	N/A	$ 2,048

fraction of total, annual project costs. Clearly, a successful computer project must budget for additional costs beyond the price of hardware and software.

Discussion of Findings by Category

The following discussion provides further detail by cost category about how these costs were derived and the implications for these findings. The discussion highlights four main cost categories: hardware, software, connectivity and support and maintenance. (A more detailed discussion of these findings can be found at www.cosn.org/tco).

Hardware

Equipment costs consume 17% - 49% of total project costs, NOT including servers and connectivity hardware, which are included under the categories, " Facilities and Renovation" and "Connectivity." (See **Table 1** for a breakdown of hardware costs by project). Hardware costs typically include computers for students, teachers, and/or administrators, printers, CD-ROM's, and scanners.

The largest proportion of these hardware costs is for student computers. Student computers specifically represented 14 - 32% of total project budgets. Perhaps surprisingly, this number is actually a bit lower than some estimates for schools in the United States. One might expect that the higher salary rates in the United States would take up a larger share of the budget and thus hardware would consume a smaller percentage of total resources than where salary rates are low. It appears that the much lower computer-student ratio in the United States, resulting from greater numbers of purchased computers, is responsible for driving up total hardware costs in the United States. A 1995 study of 8 hi-tech schools in the United States found that schools were spending 30 - 67% on hardware (Keltner and Ross 1995 as cited in Melmed, A. et al 1995).

Should schools be prepared to replace a computer every five years? The rapid evolution and relatively short life of computers suggest that they become a line item in recurring budgets. The short life of computers and software also suggests that if computers are not available later in school-life, lower school investments are not likely to be valuable. Issues that affect the exact cost of hardware include functionality of hardware, how many units, and the configuration of units.

The functionality of a computer -- processor speed, hard drive space, and memory -- affect unit cost of a computer. Age indirectly affects costs because older computers often have lower functionality. What kinds of computers are necessary for a given project depend on the type and intensity of use. High-powered computers cost more, although high-powered computers are not always necessary. Typical use of computers in K-12 schools does not require state of the art hardware.[2] While it has been conventional wisdom for several years to talk about the declining costs of hardware and computing power, evidence suggests that institutions consistently pay $1,000 - 2,000 per computer, at least over the last 5 years. While the computers being purchased today for $1,500 may be more powerful than the computers purchased 5 years ago for $1,500, off the shelf software applications often require newer hardware without providing measured educational improvements. Two alternatives to this dilemma are emerging although neither has been widely tested: software that takes advantage of lower-grade computers and "networked computers."

Networked Computers. Some efforts are being initiated to use low-cost equipment such as Network Computers (NCs, also known as thin clients and dummy terminals). Network computers do not have hard drives, so are unable to store data or applications on the computer. Instead, NC users access through their local server or, in some cases, the Internet. NC's have three major advantages:

- They cost less than personal computers.
- They require very little maintenance or technical support since they are much simpler machines.
- They do not need to be discarded and replaced by newer, more powerful computers every few years. Instead, upgrades are simply provided to the server.

There are three main drawbacks to network computers.

- There is need for more technically proficient network administrators, although fewer network administrators may be needed overall.
- Processing speed of terminals are greatly reduced when network traffic is heavy, as is likely to be the case when a class goes to the lab for an organized computer session.
- Should the server go down, all computers connected to the server lose almost all functionality, rather than just networked services.

The impact of NCs on project costs is not yet well documented, although several projects are underway. A South African distance education consortium has started using Sun's NCs for its computer centers, and Sun also is working with a number of school districts in the United States to pilot their NC systems. Sun's NC is currently retailing at about $499 and can be leased in the United States for $9.99 per month with a 5 year contract.

Student-Computer Ratios. The total number of computers purchased also influences the magnitude of total project costs. Student-computer ratios in developing countries differ dramatically. In Costa Rica, the reported average was about 53 - 73 students per computer, and in Chile the ratio was much higher with 68 to 137 students per computer reported

(Alvarez et al 1998). The range for in-country estimates depends on several factors influencing how computers are allocated. Where computers are provided centrally, laboratory size is often set at given increments. In the case of Chile, for example, 3 computers were offered to schools with under 100 students, 6 computers to schools with under 300, and 9 computers to all schools larger than 300 students. These computer-student ratios are not equivalent. Oftentimes, localities are expected to provide some computers, and in these instances, poorer and/or remote localities fall predictably behind. Thus, planners of large-scale projects should pay particular attention to addressing needs of poor and rural areas in order to encourage equity among K-12 schools. In Egypt, the planned student to computer ratio was 27 to 1 (computed from Secondary Education Enhancement Project PAD), and in Turkey the ratio is 40 to 1. Barbados planned on the lowest student-computer ratio at an eventual 3:1. See **Table 2**.

Table 2: Student-Computer Ratios in Developing Country Projects

Country	Student-Computer Ratio
Costa Rica	68-137:1
Chile	53-73:1
Turkey	40:1
Egypt	27:1
Barbados	3:1
Jamaica	n/a

In the United States, student-computer ratio has been consistently falling for at least the last 15 years from 125:1 in 1983 to 9:1 in 1996.

There are few guidelines available to help determine optimal computer-student ratios. A general tendency has been "the more the better." Administrators can estimate the likely need for computers by assessing what students will do with computers, how long it will take them to do it, whether students will work alone or in groups, and the number of hours that computers will be available in a school day or week. Where only a few computers are to be deployed in a school, administrators and the library are generally the first recipients. Where these few computers are used for instructional purposes, they are generally used as presentational aids.

In addition to the specific type and number of computers, how computers are configured will impact on cost. The choice is typically between a centralized, "laboratory" model and the more diffuse "classroom" model. Computer labs typically have from 10 - 50 terminals. They are well suited to centralized instruction, maintenance, and security. It has been argued that a centralized model does not encourage curricular integration among classroom teachers and so many valuable uses are lost. A 1995 McKinsey & Co. study found that a classroom model with a computer for every 5 students and a high-speed T-1 connection would cost about four times as much as a computer lab model in up-front investments and a little more than 3 times the per student recurrent cost. Project analysis in Egypt found that significant economies of scale were possible if larger laboratories were used. Increasing laboratory size to 22 computers from 14 resulted in 28% lower total per student costs and 35% less recurrent costs (Human Development Group Project Appraisal Document, p. 40, 1999).

Beware of Donations. It is important to note that donated computers are not free. Donations are likely to generate expenses, although very little has been documented in this area. Many donated computers are likely to require memory and hard drive upgrades to run newer software. Such upgrades can be expected to cost between $50 - 500 per computer. Further, at least one country in Africa has charged as much as $200 per donated computer for Import Duties.

Software and Content

The intended uses of the computer will also dramatically impact upon software costs. A library of software resources can allow teachers greater flexibility in their use of technology. But hosting a wide range of software applications can increase not just the amount spent on software, but the amount needed for training and support as well. At one end of the spectrum, "freeware" (for generic applications) exists and much of it can be found on the Internet at little direct cost to potential users (except telephone charges for downloading material as they may apply in specific countries). At the other end, there is custom-made and/or specialized software. Specialized software, such as that for scientific purposes, is typically very expensive with some packages costing thousands of dollars. Similarly, software in languages other than English is more difficult to obtain. Countries interested in using computers in other languages may face linguistic hurdles, and thus incur additional costs for translation and new programming. Economies of scale can be realized by centralizing the storage of CD-ROM's and other resources in a central place, such as a library, for use by many classrooms or sometimes across schools. Jamaica, for instance, created "Software Centers," within a reasonable distance of several schools. The Software Centers were used for teacher training and as a means of trying out new software before local purchase.

In the United States, experts had recommended that school systems allocate approximately $100 per student for software (President's Committee of Advisors on Science and Technology 1997). Schools typically fall well short of this figure, although Barbados estimates hit it precisely. Quality Education Data reports that the average school in the United States spent about $11.00 per student on instructional software in the 1998-1999 school year. Other research in the United States suggests that 10% or less of a school's technology budget is typically spent on software (Melmed et al 1995, and International Data Corporation www.apple.com/education/k12/leadership/LSWTF/IDC1.html). Costs in developing countries for software appear to also fall within this lower range. See **Table 1** for the total annualized per school software cost and software costs as a percent of annualized total costs. Per school estimates vary considerably; additional work will need to be done to determine the causes of such dramatic fluctuation.

The software estimates are made of two types of investments: software for instruction and network, and server and other administrative software. Instructional software is usually a much greater expense than administrative software. In Barbados, investments in instructional software are expected to account for 9% of total expenditures, whereas in Turkey software expenditures are less than 1%. Turkey continues to investigate the costs of creating specialized software and appears inclined to rely on basic "office packages" and freeware at least in the short-term. Similarly Egypt and Chile software expenses are reported at around 2% of total project costs, or US$2,000 and $350 per school, respectively. Chile's program benefited from freeware, most notably "La Plaza" a graphical interface for mail, document storage, and other computer applications (Potashnik 1996).

Budgeters and planners must also keep in mind the need for network software. Although smaller, administrative software costs are not negligible. Estimates for networking software also range considerably, from $700 per school (Egypt) to $16,000 per school (Barbados). No specific estimates for networking software were found for other projects.

Connectivity

All of the projects included funds to connect computers within a school and to connect computers across schools through the Internet. The costs of connectivity rely heavily on three factors: the cost to prepare a building for connectivity, the costs of equipment and installation, and recurrent connectivity charges.

Some of the costs necessary to prepare a building for connectivity would also be necessary for computer projects that did not have connectivity -- such as heating, ventilation and air conditioning, as well as security and power requirements. We group them here under one heading because they are often inter-related. "Several studies [in the United States] have projected the cost of building local area networks and wiring classrooms to the Internet to be roughly about $500 per student per year. However, many factors, including the age of physical plant and previous technology investments, [school size and computer student ratio] will determine the precise figure," (Taking TCO to the Classroom, available at www.cosn.org/tco). Preparing a school for connectivity will often require renovations within a building. A building must have sufficient electrical capacity, from available power to number of outlets, adequate temperature control and ventilation, and security. These costs can often be reduced if they are considered when new buildings are being constructed. There is also a wide range of wireless solutions emerging, which could further reduce the burden of some wiring costs.

Equipment costs associated with connectivity depend heavily on the type of connectivity made available to schools. Low-bandwidth connections are generally less expensive but by definition reduce the capacity of the network and how it can be used. Downloading materials in a slow network can be very costly in staff time. The California Department of Education has produced a document to help planners determine the level and costs of connectivity called "Going Beyond your Local Area Network" and is available at http://www.cde.ca.gov/ftabranch/retdiv/k12/ISDN.html. In Egypt, connectivity and telecommunications equipment cost an estimated $4,600, or $1,200 in annualized costs per school, and 3% of total school costs. In Barbados, where budgeting was done for the entire national project, $8.8 million was planned for networking equipment, or $2.3 million in annualized costs, and 8% of total project costs. Although these figures were not reported by school, it appears that about $34,000 in annualized costs was budgeted per school.

Telephone companies charge for the use of a telephone line in many countries, even for a local call. Thus schools will be paying two different types of charges: one for the use of a telephone line and another for Internet service provision. Where telecommunications are still operated by monopolies, these prices can be quite steep. The additional cost of the telephone line can dramatically influence total costs. For instance, in Turkey, a single, dedicated telephone line per school is likely to cost $80 per month, resulting in an estimated $2,400,000 per year (or 4% of total annualized project costs). The World Links Project in Ghana reports that schools are paying an average of about $86 a month per school in telephone dial-up charges for the Internet in addition to an Internet subscription fee of $100 per school. Planners in contexts such as these must think carefully about how many telephone lines per school are needed and balance cost and performance issues.

Strategies to provide low-cost Internet access are emerging. Some costs may be mitigated, at least in the short term, during the bidding process. For instance, firms supply free Internet service for one year as part of an arrangement in Turkey. Further, the major investment necessary for access---country gateways and university nodes---already exists in most countries.

Wireless is also emerging as a viable solution. Wireless systems can be terrestrial, when radio frequencies are used, or by satellite. High-speed data-links can cost less than $2,000 for a simple point to point connection over a mile or two, and these links can cost less for lower-bandwidth (IDRC 1999). Cost-components of a wireless system include: capital costs, recurring costs, and usage costs. IDRC (1999) offers the following checklist to "ensure the success of a project including wireless:"

- How much traffic needs to be transported?
- How reliable does the link have to be?
- Are there any other potential users of the system in the area that can help defray the set-up or operating costs?
- What are the characteristics of the terrain where the equipment is to be used?
- What is the required distance of the link?
- Is a license required?

Support and Maintenance

Once computers are installed in schools, users will need regular support. Also, hardware and software will require regular maintenance. The number of support staff required depends on several factors, including the number of computers, the number of software applications, and the ability of users. Schools and ministries have often been innovative in the way they provide support and maintenance. In Chile, engineering school faculty from a nearby University largely provided technical support. Maintenance costs were estimated at 10% of equipment costs, or 9% of the total annualized budget per school. Turkey has included maintenance in its hardware bids. Bidding vendors have budgeted for between 3 and 7% of total hardware costs over a 5-year contract. Similarly, a flat rate of 5% of equipment costs was budgeted for maintenance costs in the Barbados project. No information was available regarding how these funds would be deployed. In Egypt, maintenance costs were anticipated at 4% of total costs, or $300 per machine per year. Again, no information was available regarding how these funds would be deployed. Jamaica estimated that $25,220 was spent to maintain computers in 23 schools over two years, or about $550 per school per year.

Students and their parents also have a role to play in maintaining equipment. For instance, the role of the PTA (Parent Teacher Association) is typically to raise funds for computer up-grades, computer personnel, and supplies. In both Chile and Costa Rica, "parents and other private individuals or locally-based companies have provided telephone lines, air conditioning, and other equipment free of charge to the schools" (Alvarez 1998, p. 9). In addition, students have contributed to basic trouble-shooting and can be trained to participate in the upkeep of computers. "The Chilean computer program has encouraged schools to appoint older students with a special interest in computers as 'monitors' or computer assistants" (Alvarez 1998, p. 15).

Inadequate support costs schools too. A detailed cost analysis was undertaken in Fairfax County, VA. "Fairfax County is a large district in the suburbs of Washington, DC, with 155,000 students and 26,000 employees. It calculated that if every teacher spends at least one hour a week trying to fix their own computer problems, that equals 307 full-time equivalent positions, at a cost to the district of $15.3 million in lost teaching time. In addition, if 5 percent of teachers are regarded as 'technical wizards' by their peers, and are asked to provide 1.5 hours a week of informal support, which equals 23 full-time equivalent positions, at a cost of $1.2 million. Thus, the district concluded that its 'hidden' costs for technical support could amount to an estimated $16.5 million" (, http://www.cosn.org/tco/checklist/support.html).

Conclusions

Two main conclusions are apparent from the review of data. First, hardware is not like other capitol goods because it has a much shorter life span than typical capital goods. As a result, hardware should appear as a line item in school-authority budgets. Next, while little guidance is available, it is clear that hardware is just a fraction of the total costs of computer projects. Budgeting authorities must be aware of these hidden costs for computer projects to be successful.

Policy-makers everywhere need more solid information about models of technology deployment in education and their related costs. The apparent paucity of good, comparable data on donor financing of technology projects and their impact suggests a fruitful area for future donor collaboration. Research activities ought to seek answers to three primary questions: What are the investment and recurrent costs associated with the use of learning materials in formal education systems around the world today? How are these costs likely to vary across regions and countries at different stages of development? What do we know about the relative cost-effectiveness of learning materials in particular settings?

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[1] All currencies were converted into US$ using exchange rates that were either the average exchange rate for the year of expenditure or a current exchange rate for on-going, recurrent, or contemporary expenditures. Using the ingredients approach specified in Levin (1983), inputs for each project were specified, and then market prices were associated with each item. Capital and other investment costs were annualized at a rate of 10%. While 10% might appear high for many countries, it is becoming a somewhat standard proxy in the field of cost analysis.

[2] The World Bank has compiled generic procurement specifications for hardware at http://www.worldbank.org/html/fpd/telecoms/procurement/hw_config.htm. Although not education specific, the pages may be helpful in that they "contain equipment specifications that World Bank borrowers can use in preparing bidding documents for procurement under World Bank guidelines. They also contain direct links to the offerings of the IT industry. As equipment specifications and product life cycles are quite short in the IT industry, we propose that the industry commits to review the generic specifications and suggest changes that may be due from time to time. The industry will have the option of adding links to sites where Bank borrowers can find information on actual offerings for each product category and price ranges (for budgeting purposes)."