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EDUCATION AND COMPUTERS: VISION AND REALITY

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An earlier (and rather different) version of this monograph was prepared as a report for the symposium "Computers and Education: The Role for International Research", held at Stanford University School of Education, March 10-14, 1986, co-sponsored by the Stanford International Development Education Committee and UNESCO. However, the opinions expressed in this monograph should not be attributed to either organization. They are solely the authors'.

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(EXECUTIVE SUMMARY)

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We are in the midst of potentially enormous worldwide change in the *way* goods and services are produced, *where* they are produced, and *what* is produced and consumed. Much of this change has been attributed to the "information revolution," since the basis of many of the transformations taking place are associated with the much more rapid flow of information and the much greater capacity for its storage.

Computers are fundamental to such changes. Computers have become exponentially smaller and cheaper and their problem-solving potential exponentially greater over the last twenty years. This has made them available in almost every country for uses almost undreamed of a generation ago. Two of these uses have been to prepare young people in school for jobs working with computer technology and to enhance and shape the learning capability of children in school.

Much has been written and promised about the role of computers in education (see for example Papert, 1980; Williams and Williams, 1985; see also Cuban's (1986) history of educational media in the classroom). There are two arguments made for their increasing importance as tools for learning: The first things on the need to develop the kinds of skills and knowledge that will allow youth to find good jobs in a changing, increasingly information based *national* economy. New skills and knowledge, it is contended, will allow economies to be competitive in an increasingly information based *international* economy. This argument makes implicit assumptions about the changing nature of national economies and the resultant demand for labor skills, as well as about the direction of international competition and the changing world economy. Namely, it assumes that (a) the principal source of future economic and social development will be the production and consumption of information, including its application to the production of other goods and services; (b) this production and consumption will significantly increase the aggregate demand for higher levels of skills; i.e., it will tend to reskill rather than deskill labor; and (c) the use of computers in schools is directly related to the development of the types of skills needed to fill these future jobs.

The second argument for computers in schools hinges on the capability of computers to improve the *overall* level of student achievement (not just computer literacy or computer related skills). One line of analysis (Papert, 1980) goes farther to claim that interactive computer based learning can change human thought structure. Again, the argument is based on implicit and explicit assumptions: in this case, they are about the nature of the learning process, the affinity of children to machines (implicitly that children learn differently with computers than with teachers alone), and about the systematicity and potential multi-dimensionality of computers as interactive, individualized tutors.

This book evaluates these arguments. It compares claims about computer education to actual outcomes by reviewing the growing body of empirical literature that treats computers' educational and labor market roles. In addition, it examines two other aspects of computers in education: the *distribution* of computers among nations and within national school systems, including the implications (if any) of this distribution for national development patterns and individual success in changing economies; and the *cost effectiveness* of computers (in comparison with "lower" technologies) for increasing pupils' achievement. Interestingly, the discourse on computers in education has made few explicit claims for either of these aspects. Computers have not generally been tauted by their proponents as potential equalizers of opportunity for disadvantaged students; nor -- despite rapidly declining hardware costs -- has the microcomputer been explicitly discussed as a particularly low-cost educational solution for raising student performance. Yet, despite the focus of information technology visionaries on the absolute effects of computers in schools, we show that a better argument can probably be made for computers in education on these distribution and cost-effectiveness grounds than in terms of their job preparation changing the way students learn.

HUMAN RESOURCES AND COMPUTER SKILLS

The empirical research in the United States suggests that even with the rapid growth of the microelectronics industry and industries that are tied to microelectronics, such as computer business services, the number of jobs requiring higher levels of computer training -- those normally associated with programming skills and a more intimate knowledge of how computers work -- are growing rapidly, but will continue to represent only a small fraction of the total new jobs in the economy for a long time to come. Further, although in the United States and other developed countries jobs working *with* computers or machines with computerized elements already represent a much higher fraction of all jobs (in the U.S., some, like Yourdon (1986), have argued that by the year 2000, 80 percent of jobs will require computer literacy), most of these jobs require a minimal amount of computer-related training and this training can be and is being provided on the job. The importance of "computer literacy" training in schools for this vast majority of computer-related jobs is therefore questionable, although no study has been undertaken until now that relates computer access in school to income or the type of job taken in the labor force. Thus no definitive claims can be made as to the importance of computer literacy in job access or productivity.

These results should be taken seriously in the United States and in other countries, but they also should be interpreted carefully. On the one hand, whereas the results show clearly that the spread of computer technology will not produce a mass of high technology occupations requiring high levels of programming another computer skills, there is little doubt from the experience of the developed and newly-industrilizing countries, that an economy wishing to participate meaningfully in microelectronic production and its application to other industries will have to develop significant numbers of specialists with computer programming and engineering skills. To develop and train these specialists will require a much larger number of young people to have access to computers in high schools and perhaps in middleschools. In developing countries it will also require more time and better training methods than are currently being used indeveloped countries because of the lack of availability of computers outside of schools. It is precisely outside of schools in developed countries that the most highly skilled computer programmers are developing themselves. But this computer rich context of countries such as the United States is not the context of most developing countries, even the more developed ones that have already entered the microelectronics sweepstakes.

On the other hand, the lack of computers in the society at large also impacts decisions about computer literacy. An argument can be made that in lower income societies with relatively few computers available to the population through private ownership, the only possible way to develop a computer-literate labor force (even when the levels of computer literacy required for many of the new jobs are quite low by developed country standards) is to make computers available in schools. In that interpretation of the results for the U.S., the reason that it is so relatively easy to train people for most jobs using computers is that the general presence of computers in society makes almost all young people and many adults necessarily more computer literate than in societies that have relatively few computers. Nevertheless, even if that is the case, the counter argument can be made that software will tend to be increasingly "user friendly," so much so that almost anyone, even those totally unfamiliar with computers can be easily and quickly trained to use them. This is clearly the trend. Furthermore, it appear that the kinds of skills associated with the somewhat more sophisticated "computer literacy" uses of computers that are general "skill" training in the computer applications word-processing, spreadsheets, feeding and extracting information, and factory applications-include a much more important element of traditional skills, such as typing, accuracy, working with complex machines, and statistical and math skills. These are much more the product of overall quality in the educational and job-training system than in the availability of computer education. It can also be argued, given the trend toward simpler software, that the principal reason for locating the production of goods and services that employ computers in a particular place is not necessarily the computer skills of the labor force there, but the level of wages relative to the level of education, irrespective of computer training.

All this suggests that the use of computers in high schools and universities to develop the high-skilled engineers and technicians needed for high tech production and certain aspects of high-tech microelectronic applications may make sense as part of a strategy of ensuring some meaningful participation in the growth of new forms of industrialization, commerce, and services. Such participation will, however, take much more than just making available programming courses for high school students. It will require secondary and university education much more geared to physical sciences, mathematics, and their applications. It will also take the development of clever industrial and social policies, including export promotion and appropriate macroeconomic measures consistent with changing global trade and investment patterns.

The argument for investing in computer education for computer literacy is much less clear, unless early computer literacy is seen as a means of promoting later (high school) involvement in more sophisticated programming courses. For most countries, computer literacy may be an expensive indulgence with rather low pay-offs. It can be argued that in low-income countries with few computers easily accessible to the public at large or even in the workplace there is a need to familiarize young people with computers in the schools as part of their general preparation for an information future, a preparation that they will not gain elsewhere. But is there really such a need? Will computer literate youth bring computer industries or computer applications to low income economies, or will other factors (low wages, relatively high levels of general education and industrial training, and competent managers) be much more important?

These are all still speculations, however, until more research is conducted on the relationshop between computer education and the pay-offs in the labor market to those who get different levels of computer access. In many countries, such studies will take some years to conclude, since there are relatively few jobs requiring any computer education, in school or on the job. But a wide range of examples, from Mexico to Brazil to Korea to Taiwan to India can provide comparative results in the context of a variety of experiences. Since computers are being incorporated differentially into these different societies, such research should also provide the basis for analyzing different ways to teach computer skills in various contexts.

COMPUTER MEDIATED LEARNING AND EDUCATIONAL POLICY

Although the evaluations of the social and economic impacts of computer use in education have only begun recently, there have now been two decades of research on the effects of computer-mediated instruction. In large part this is the outcome of influence exerted by computer visionaries like Papert fascinated with the implications of computer human interaction for changing the learning environment, and the more "practical" technology in the classroom" types like Suppes who saw computers as an effective way to raise learning curves of standard subjects such as math and language skills.

The evaluations that have predominated have been of computer-assisted instruction (CAI), where reading and math achievement are the outcome measures. According to our review, these studies show a number of significant results: (1) drill-and-practice sessions of limited duration over an extended period of time do increase reading and math scores of primary school students; (2) where achievement gains of CAI relative to other forms of instruction have been the focus of research, CAI proves to be an effective supplement to classroom teaching; (3) in comparisons of different modes of CAI use, there appears to be as lightly greater cognitive gain at the high school level when the computer acts as a complete substitute for teacher, textbook, etc. than when the computer acts as a supplement, but not at the primary level, where the opposite is the case; (4) there appear to be greater gains for those pupils with lower academic skills than for those with higher (which implies that the computers may serve as an "equalizer" of learning possibilities for disadvantaged students); (5) computers are not particularly better at raising math over reading scores -- some studies show larger increases in math scores and others, in reading scores; (6) there appears to be a declining effect of CAI, the longer the length of instruction; and (7) there seems to be no clear indication which aspect of CAI most directly affects these gains, i.e. software design, intensity of contact, external reinforcements of CAI material, and so on.

But there have also been evaluations in the U.S. of LOGO (problem-solving) applications. Unlike the CAI evaluations, which show a clear trend, the LOGO studies show mixed results. Some suggest significant gains in problem-solving, skills including gains in divergent and reflective thinking. But a major two-year study of LOGO found no significant effect on cognitive skills. Neither do any studies sustain Papert's claim that learning with LOGO-type programs will create new conceptual skills in children.

Research on the motivational effects of computers on learning is even more limited than on its cognitive effects, but available recent studies (again, in the U.S.) suggest that several aspects of modern tutorial software, particularly the fantasy element, could make the subject matter intrinsically more interesting and hence could increase learning. Furthermore, other studies indicate that motivation to learn particular subjects is increased in the CAI environment.

Does this mean that countries, states, and school districts making the decision to put computers in schools for general instruction should go for drill-and-practice and supplemental computer applications and avoid more teacher-independent, problem-solving software? Although this is the direction suggested by evaluations to date, there are enough problems with such evaluations to merit both caution and considerably more research, particularly in non U.S. settings.

The fact that most LOGO evaluations have been carried out in the U.S. setting may have prejudiced results of LOGO assessments: since curriculum and teacher training in the U.S. is drill and practice-oriented, problem-solving CAI should probably be evaluated in a curricular setting that stresses such an approach (for example, in a European-type educational system). Furthermore, it is easier to design and implement good drill and practice software than problem-solving software, although those teachers who are best prepared to work with computers in the schools appear to prefer the latter to the former.

What seems to be lacking in all of these studies is an underlying theory of learning that can explain why or why not computers will enhance learning. Papert's seminal work is as yet unsupported by firm data. Fabulous claims of computers' effect on the educational process have not been observed in the real world. Yet this may be true because of the way computers are being used in the educational process and because learning with computers is just at the beginning of its applications. Such effects may take a generation or two to be felt. What educational technology may do is to provide a less "restricted world," a world in which more cognitively significant experiences are available.

What about CAI itself? Are the results convincing that CAI will yield high gains in language and math skills everywhere? Are the CAI results universal or only relevant in an educational system which stresses learning through repetition? Again, the fact that the studies are also highly concentrated in a particular setting suggests caution in projecting the results to other countries. Little information exists about the relative effectiveness of different kinds of applications in education in different learning settings.

Thus, in all areas of exploration concerning the educational effects of computers, cultural context requires greater attention. The learning styles that characterize education both inside and outside of schools may have as much to do with what students learn from computers as software features. The definitions of learning implicit in instruments used to measure it may not be appropriate across cultures. Among all of the areas of research on computers and education, computer effects on learning may be the least generalizable to different social and cultural contexts.

COST EFFECTIVENESS OF COMPUTERS IN EDUCATION

Nevertheless, in the United States, CAI applications look promising to improve learning speed, and to improve the relative learning speed of disadvantaged children. Does this mean that schools should invest more heavily in computers? To make this decision, we looked at the *cost-effectiveness* of CAI, in addition to the effects on learning. Cost-effectiveness tells us how computer-assisted instruction compares to other interventions not only in terms of effects but in terms of relative costs.

In this comparison, CAI appears to do well, but not as well as peer-tutoring. In terms of cost-effectiveness, then, using computers as a teaching supplement may produce better results per $100 of investment than reducing class size or increasing instructional time. But peer-tutoring under present conditions of computer usage is much more cost-effective than any of these interventions. Given these results, and focusing on the single objective of improving reading and math achievement, schools would do well to increase peer tutoring and reduce CAI.

There are several caveats to these results. First, CAI may have more potential to improve its cost-effectiveness in the future than other interventions because of improved software, more effective applications, and so forth. Improvement potential may be much smaller with simpler technologies. Second, there are other objectives to technologies than just raising learning speed: in the case of computers, CAI also introduces pupils to the computers themselves and may end up creating both interest and skills that carry over into the job market. Peer tutoring, on the other hand, may create greater interest in learning and schooling than other technologies.

Furthermore, these results apply to the United States. In other countries, costs of computer education relative to the cost of other interventions may be very different than in the U.S. The skilled labor needed to service and manage computer education interventions may be in much shorter supply; educational software in the local language difficult to find; and teachers even less prepared to use computers effectively in the classroom. Other interventions not included in the U.S. comparisons, such as textbooks or educational radio, may be very relevant in low income developing countries, whereas they are not relevant to a developed country educational setting. Smaller classroom size (since the number of pupils per teacher in many countries is considerably higher than in the typical U.S. classroom) may also have a greater effect per unit of cost than computers.

The meaning of all this is that cost-effectiveness results are very sensitive to educational/economic settings. Even in the United States, there is some controversy over whether present cost-effectiveness ratios reflect what they *might* be under changing software and other conditions for CAI. If we try to apply these U.S. results to decision making in a totally different resource-availability situation, the error possibilities would increase accordingly.

Each country should therefore undertake its own cost-effectiveness studies and use those studies to make its particular educational technology decisions. At present these studies are essentially non existent.

WHERE DOES THIS LEAVE US?

This assessment allows us to begin to reach some conclusions about computer education: (a) There is little, if any, evidence that computers in schools used for general education actually help individuals get better jobs. (b) There is little direct evidence that computerizing a school system will help national economies become more competitive. (c) There is some evidence for the U.S. at least, that computers can enhance learning. (d) Computers seem to be more cost-effective than some alternative technologies, but less so than others, such as peer tutoring. (e) There is evidence that the disadvantaged significantly improve their school performance with computer assisted instruction, but that they are less likely to get enough time with computers in and out of school to prepare themselves for professional, high technology jobs.

Computers in U.S. schools seem to make sense in terms of teaching programming skills to a broad base of pupils in middle school and even primary school with the intention of stimulating interest in advancing to higher levels of programming and programming applications to science and math. Computers probably also make sense in teaching vocational skills such as word and data processing in high school. The arguments for CAI and general computer literacy are less persuasive, particularly in terms of cost-effectiveness, but in the CAI case could become more persuasive if ways are found for CAI to make a larger impact on learning for the same or lower cost. With improved software and improved teacher preparation, effects could rise.

None of these conclusions (as tentative as they are) may hold for other countries, although we suspect that predictions can be made about the value of educational computers in developing countries in terms of their labor market applications by knowing something about actual and planned changes structure of industry and trade in a given country. Much less can be said about the learning effects of computers in other countries, nor about the type of approach to learning (CAI versus LOGO) which would be most effective. Until much more research is undertaken and its results available and assessed, decisions about bringing computers into the schools to prepare youth for an uncertain future will be made for many of the wrong reasons.

Despite this sobering analysis, however, there is also evidence that the world economy is changing. Information based technologies have become a key to productive innovations and an important source of new employment. It appears that countries need some minimum level of investment in computer programming and enginnering training to participate in this significant economic change. So even though computerizing education as a whole does not seem to result in more or better jobs for the average pupil, there is a potentially highly-skilled group of programmers and engineers who are needed and might be trained by considerable investments in computer-based education, especially in secondary school.

How should policy-makers decide whether computer education will achieve the particular objectives they have in mind? This study reviews a number of analyses that have already been done and that could and should be reproduced in the specific conditions of each society. We conclude that the impact of computers is controversial enough that such research should be carried out before any large scale investment is committed. Furthermore, even if computers are to be used in education, the *way* they are used should depend primarily on their effectiveness in achieving well defined objectives. These objectives may vary substantially from society to society. Evaluations must therefore be tailored to specific situations.

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A number of people -- in addition to the present authors -- contributed to that report: Robert A. DeVillar researched much of the earlier work on access to computers in the United States; Francoise Herrmann researched the limited available data on computers in education outside the United States; Margaret Sutton worked on aspects of the effectiveness of computers in improving school performance. A special thanks is due to Elise Ann Earthman, who typed the manuscript onto computer discs and tied together all our diverse reference material into a coherent bibliography.

At the conference itself, participants responded to the report and provided feedback. We would like to thank them for helping us reconstruct some of the arguments so that they made sense in an international context. A special thanks to our Stanford colleagues Robert Hess, Henry Levin, and Decker Walker, who read this version of the manuscript and provided constructive comments.

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Chapter I

INTRODUCTION

We are in the midst of potentially enormous worldwide change in the *way* goods and services are produced, *where* they are produced, and *what* is produced and consumed. Much of this change has been attributed to the "information revolution," since the basis of many of the transformations taking place are associated with the much more rapid flow of information and the much greater capacity for its storage.

Computers are fundamental to such changes. Computers have become exponentially smaller and cheaper and their problem-solving potential exponentially greater over the last twenty years. This has made them available in almost every country for uses almost undreamed of a generation ago. Two of these uses have been to prepare young people in school for jobs working with computer technology and to enhance and shape the learning capability of children in school.

Much has been written and promised about the role of computers in education (see for example Papert, 1980; Williams and Williams, 1985; see also Cuban's (1986) history of educational media in the classroom). There are two arguments made for their increasing importance as tools for learning: The first hinges on the need to develop the kinds of skills and knowledge that will allow youth to find good jobs in a changing, increasingly information-based *national* economy. New skills and knowledge, it is contended, will allow economies to be competitive in an increasingly information-based *international* economy. This argument makes implicit assumptions about the changing nature of national economies and the resultant demand for labor skills, as well as about the direction of international competition and the changing world economy. Namely, it assumes that (a) the principal source of future economic and social development will be the production and consumption of information, including its application to the production of other goods and services; (b) this production and consumption will significantly increase the aggregate demand for higher levels of skills; i.e., it will tend to reskill rather than deskill labor; and (c) the use of computers in schools is directly related to the development of the types of skills needed to fill these future jobs.

The second argument for computers in schools hinges on the capability of computers to improve the *overall* level of student achievement (not just computer literacy or computer-related skills). One line of analysis (Papert, 1980) goes farther to claim that interactive computer-based learning can change human thought structure. Again, the argument is based on implicit and explicit assumptions: in this case, they are about the nature of the learning process, the affinity of children to machines (implicitly that children learn differently with computers than with teachers alone), and about the systematicity and potential multi-dimensionality of computers as interactive, individualized tutors.

This book evaluates these arguments. It compares claims about computer education to actual outcomes by reviewing the growing body of empirical literature that treats computers' educational and labor market roles. In addition, it examines two other aspects of computers in education: the *distribution* of computers among nations and within national school systems, including the implications (if any) of this distribution for national development patterns and individual success in changing economies; and the *cost-effectiveness* of computers (in comparison with "lower" technologies) for increasing pupils' achievement. Interestingly, the discourse on computers in education has made few explicit claims for either of these aspects. Computers have not generally been touted by their proponents as potential equalizers of opportunity for disadvantaged students [1]; nor -- despite rapidly declining hardware costs -- has the microcomputer been explicitly discussed as a particularly low-cost educational solution for raising student performance. Yet, despite the focus of information technology visionaries on the absolute effects of computers in schools, we show that a better argument can probably be made for computers in education on these distribution and cost-effectiveness grounds than in terms of their job preparation or changing the way students learn.

In Chapter 2, we review the arguments for computers in education and the actual applications of computers in the real world, including distributional questions. Our analysis here was greatly aided by the Colloquium held at Stanford University in March, 1986: there, experts on computer education provided important insights on the use of computers across many countries of the world, and the issues being discussed in those countries regarding their use.

Chapter 3 examines the increasing body of analyses and data measuring the effect of information technology on employment and skills. Are future employment and skills closely tied to computer education? Are those who argue that the future world economy will need large increases in highly computer-skilled workers to produce new products and the old products in new ways correct? Will those national economies that develop computer-related skills in their labor forces most rapidly be most competitive in this emerging world economy?

In the fourth chapter, we assess the effects of computers in learning, focusing on the assumptions usually made and -- furthermore -- also reviewing the growing body of literature that measures the impacts on learning of different applications of computers in schools and for different groups in school, particularly the disadvantaged.

In Chapter 5, we analyze the available data on the cost-effectiveness of computers in schools, comparing the cost-effectiveness of different configurations used in computer education and also comparing the cost-effectiveness of computers versus alternative, "lower" technologies.

This assessment, together with the distributional patterns and the cost-effectiveness analysis, allows us to begin to reach some conclusions about computer education: (a) There is little, if any, evidence that computers in schools used for general education actually help individuals get better jobs. (b) There is little direct evidence that computerizing a school system will help national economies become more competitive. (c)

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[1] Suppes' early work and applications were oriented toward disadvantaged groups, and, indeed, the results of his evaluations showed high gains in math scores for such groups. But our point is that educators have not focused on the equity aspect of computer applications.

There is some evidence for the U.S. at least, that computers can enhance learning. (d) Computers seem to be more cost-effective than some alternative technologies, but less so than others, such as peer tutoring. (e) There is evidence that the disadvantaged significantly improve their school performance with computer-assisted instruction, but that they are less likely to get enough time with computers in and out of school to prepare themselves for professional, high technology jobs.

Despite this sobering analysis, however, there is also evidence that the world economy is changing, and this may alter significantly many of the results that we report here. Information-based technologies have become a key to productive innovations and an important source of new employment. It appears that countries already need some minimum level of investment in computer programming and engineering training to participate in this significant economic change. So even though computerizing education as a whole does not seem to result in more or better jobs for the average pupil, there is a potentially highly-skilled group of programmers and engineers who are needed and might be trained by considerable investments in computer-based education, especially in secondary school.

How should policy-makers decide whether computer education will achieve the particular objectives they have in mind? This study reviews a number of analyses that have already been done and that could and should be reproduced in the specific conditions of each society. In the conclusion to the book, we propose a research agenda detailing the analyses that would be most useful in assessing computer education in such contexts.

Nevertheless, it would be naive to believe that decisions to invest in computers will be made only after undertaking exhaustive studies which evaluate the costs and benefits of such decisions. In the absence of specific research, then, policy-makers should pay particular attention to the available results presented here. They are highly suggestive of what the pay-off and limits are to computers in schools and can serve as a baseline approximation for deciding how and how much to invest in such new technologies.

Chapter II

THE DISCOURSE ON COMPUTERS IN EDUCATION

Computers are rapidly being installed in schools for teaching computer literacy, for computer-assisted instruction in reading and mathematics, and for specific computer-programming courses. The growth of computers in schools is based on a vision of improving pupils' school performance, of preparing young people for changing job demands in the workplace, and of altering the way children learn.

Yet, this vision does not necessarily fit the reality of what computers are achieving in schools. There is great variation from country to country in the number of computers in schools, the levels of schooling in which computers are being used, and the degree to which they are being used effectively. There are differences among countries in the goals of computer education. There are also significant differences in the access to computers by different social class groups and girls and boys. Finally, there is a potentially large difference between what the new technology promises to education and what it can and will deliver in practice. All of these issues constitute the discourse on computers in education.

In this chapter, we review some of the arguments in favor of computer use in schools, particularly from a pedagogical perspective. We discuss how computers are being used in schools, how they are distributed among and within countries (to the degree that data are available), and some of the possible impediments to their effective use as educational tools.

ARGUMENTS IN FAVOR OF COMPUTER USE IN SCHOOLS

Educators have been faced by an optimistic vision of computer uses in education for more than twenty years. As early as 1962, business educators in the U.S. were describing the now-familiar virtues of computer-based learning experiences:

> they condense extensive decision-making experience into short periods of time; they emphasize the need of reaching decisions with the incomplete data at hand; they give role-playing experience; they make possible playback of training activities; and they induce feelings of participation. (Plattner and Herron, 1962)

Although some educators dismissed such innovations as "fads" (Smith & Smith, 1966, p.227), others anticipated future computer learning systems which integrate "material from the general cultural data bank, from the learner's own past responses and from the discontinuous symbolic storage" into holographic, multiperson learning dialogues (see Leonard, 1968, chap. 8, pp. 140-155). Fueled by commercial interests, computer specialists, and the popular communications media, the microcomputer rapidly superceded the mainframe as the proposed key to global educational success. "The technological revolution," it is believed, "will make it possible to conceive of a unique network of education, which, while respecting local and cultural differences, will be based on common structures." (Attributed to Tinbergen, in Servan-Schreiber, 1980, p.269).

To understand the concepts which underlie this vision, it is helpful to examine some developments in teaching and learning in the field of educational technology. Both radio and television were once welcomed into education with high hopes for revolutionary changes that failed to materialize (Tyack, 1985; Levin and Meister, 1985). The state of the art through 1966 is well documented in Smith and Smith's text book, *Cybernetic Principles of Learning and Educational Design.* Wittich and Schuller's text, *Instructional Technology: Its Nature and Use*, published in 1973 (fifth edition), gives only a slightly more modern view. By this time electronic data processing was well established in the business offices of many of the larger school districts in the United States and students were beginning to get their hands on minicomputers and mainframes in high schools and colleges. Both the literature and the reality of educational computing grew rapidly during the first half of the 1970's ([2]). By the time the Datapoint "Intelligent Terminal" and the MITs Altair Microcomputer Kit arrived on the American market in 1974 and 1975, forward-looking educators were more than ready for a new technological answer to educational problems.

Three independent threads have run through the vision of educational computing since its inception. The first, computer assisted instruction (CAI), grew out of early work on self-scoring tests and mechanical teaching machines by S.L. Pressey in the 1920s (Smith & Smith, 1966). Further development by Pressey and others was supported by the U.S. military and incorporated electronic components as they came along. Major theoretical foundations were supplied by B.F. Skinner's techniques of operant conditioning (Skinner, 1953). The design of modern computer assisted instruction programs draws heavily on subsequent research on programmed learning materials implemented in a variety of media (see Smith & Smith, 1966, Chap. 10). Extensive research on specific implementations of computer-based programmed curriculum has been carried out by Computer Curriculum Corp, Plato, and TICCIT -- to name just a few.

Computer science, and specifically programming as a school subject, became a second major thread spun by proponents of computer use in schools. American educators, such as Dwyer and Critchfield (1978) and Luehrmann and Peckham (1984) felt that, "you cannot use a computer without giving it instructions - that is, programming it." (p. x) Thus "programming" and "computer literacy" were deemed synonymous. This was an entirely reasonable attitude at a time when application programs were virtually non-existent outside the field of business data processing. But, more recent developments in software have lead to further differentiation of school courses offerings which employ computers. These developments will be discussed further below.

Enhancement of cognitive development and problem-solving skill was the third expected result of working with a wide variety of computer-based activities. Theoretical expositions, such as Brown & Lewis' "The Process of Conceptualization" (1968) and Papert's *Mindstorms* (1980), have enjoyed an enthusiastic reception by educational practitioners in spite of the research community's inability to demonstrate a measurable

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[2]. see, for example, Kemeny, 1972; Albrecht, Finkel, and Brown, 1973; Nelson, 1974; and Rockart and Morton, 1975.

cognitive gain as predicted. (See, for example, Pea, Kurland & Hawkins, in Chen & Paisley, 1985; Perkins, in Soloway & Iyengar, 1986.)

Most of the pro-computing arguments reviewed above were well developed before the invention and subsequent popularization of the microprocessor and its enveloping system, the microcomputer. But the microcomputer provided a whole new set of reasons why educators should adopt and adapt this latest technology.

The low cost of the microcomputer, especially in comparison to its mainframe and minicomputer predecessors, has permitted its worldwide diffusion into the educational sector. Computing costs have consistently fallen 30 to 40 percent per year. When compared to the costs of other technologies, this makes the apparent expense of computing remarkably small. If the automotive industry, for example, had experienced a similar downward cost trajectory, a Cadillac limousine costing $7,500 in 1957 would today cost 3 cents rather than $40,000 (Kotlowitz, 1985). Data storage has followed this same pattern. A computer can now store one million bits of information (roughly 125,000 characters) on a flexible diskette for approximately $2.50.

The spread of microcomputer use into the lay community has created a demand for flexibility in both hardware and software. Modern software is designed for access and manipulation by generally educated individuals rather than by a team of specialists. A total microcomputer system fits comfortably within the confines of a work-desk. The system components are familiar: a typewriter-like keyboard and printer, diskettes and drives which are analogous to records and their players, and a television screen. Compared to its predecessors, the microcomputer is much less sensitive to environmental conditions, so that it can be used in the home, school, factory, or office without special clean-room environments, raised flooring, or controlled climatic conditions.

These changes in system design lead to two very different changes in the characteristics of the user population. On the one hand, "user-friendly" software makes computer tools accessible to literate workers with minimal computer training. On the other hand, the amount of informal and self-guided training undertaken by most computer users is both large and immeasurable.

Yet another attribute is the microcomputer's patience coupled with its accuracy and interactiveness. It does not tire of waiting for the student to make an entry, correcting the student's mistakes, or instructing the student yet another time in the area needing correction. If a student types in an incorrect response, it is rejected with a brief comment or perhaps a loud "beep." Microcomputer software is capable of many alternative responses, ranging from doing and showing nothing (an implicit command to "try again"), to branching (a term which refers to providing remedial instructional steps which bring the learner up to the present level of expected knowledge or jumping ahead to levels of knowledge appropriate to the user's level), to graphics illustrating the computer's reaction to the user's error, to a simple, yet unintelligible error message. The ability to interweave meaningful messages into an interactive computer program is being exploited in the business and professional world as well as in educational institutions. New commercial software (the WordPerfect wordprocessor, for example), is often shipped with an "on-line tutorial" which uses computer-assisted instruction techniques to teach the use of the software to the purchaser.

The microcomputer's perceived low-cost, functional design, projected performance and potential to motivate students, coupled with the relative ease of moving the system from one location to another (portability), have made its presence appealing to many within the educational sector. There are also those inside and outside education who see computers being used increasingly in work. They consider that computer education will serve not only educational goals but will help prepare young people for living and working in a computerized, "information" society. Computers in schools, in that view, will be both object of study and will help create *new ways* of thinking which are appropriate to the information society.

This is the vision promoted by the growing numbers of proponents of computers in education. Yet there are competing perspectives to this vision. Questions concerning the elements described above have been posed, new arguments introduced, and counter-interpretations made regarding the benefit of computers in education. In many cases, the less sanguine perspectives are based on empirical studies rather than utopian predictions, lifting the arguments and trend-possibilities out of the realm of speculation and placing them squarely within reality.

Is the promise of computer technology fundamentally different from that of the other technical innovations offered to education over the years -- books, blackboards, radio, films, language labs, and television? Each technology promises to revolutionize education by "freeing the teacher to do what only teachers can do - engage in the humanization of instruction and learning," (Wittich & Schuller, 1973. p. 40). Certainly books and blackboards have become part of the expected paraphernalia of the formal classroom in many parts of the world. They seem to have fulfilled their promise. But, as historian, David Tyack notes, "in successive waves of four to eight years, the number of articles on radio, film, television, and programmed instruction tended to peak and then fall off as a new cure-all appeared," (Tyack, 1985). The verdict is not yet in.

HOW ARE COMPUTERS BEING USED IN EDUCATION TODAY?

So far we have noted three traditions of educational thought concerning computers: teaching machines, computer science and vocational training, and thinking skills. A more accurate division of the way computers are actually used in education is a dual one -- computers as an *object of instruction* and computers as a *means* of instruction (Walker, 1984). Typical computer-as-object topics include word processing and data base management as well as computer programming in a variety of computing languages. Some schools may also offer computer maintenance or digital electronics as part of a vocational or technical course of study. *Computer literacy* is the largest subset of computers-as-objects: both young people and adults are trained to work with computers in order to prepare them for work and living in an "information society." In such a society, becoming familiar with computers and how they work is as much a part of a person's education -- in this argument -- as learning to read and to do simple arithmetic.

Included in the computer-as-means category are: drill and practice sessions that exercise a student's skills, usually in a subject other than computing; intelligent tutorial and diagnosis systems that teach new subject matter and/or identify gaps in student knowledge; simulations and games that provide activities to supplement traditional classroom instruction in a subject; and finally, problem solving or logical thinking skills development wherein the computer and software serve as a laboratory for exercising a student's reasoning power.

Computers as an Object of Instruction

Computing is often treated as a separate instructional subject, taking its place alongside more traditional disciplines such as literature, history, mathematics, or engineering. Schools often introduce computing first as an adjunct to a math or business course and only offer separate computing courses after considerable interest in the subject has developed within the student body.

Two rationales for introducing students to computers as objects of instruction predominate: employment-readiness and improved development of students' problem solving/logical thinking skills. Employment training may also be divided into two areas: computer programming and vocational education.

We will deal with the relationship between computer education and jobs in more detail in the next chapter. But it is worth noting that the argument for computers in schools has shifted markedly in recent years toward the employment objective from the programming skills objective. For one thing, a very small percentage of jobs, as we will show, uses programming skills. These are very crucial jobs in the information and computer economy, but they are few in number. Secondly, computers for consumption purposes are not attaining the same role as other media -- interaction technology is primarily a work tool. Thirdly, computer software is getting easier to understand -- it is more "user friendly," and as it becomes so, computers require less training to work on, not more.

Nevertheless, vocational educators are training more and more students in business and office occupational skills which require computer operation and in computer maintenance and repair. These, along with the relatively smaller number of programming-related jobs are projected to be among the 9 fastest- growing jobs between 1982-1995.

Vocational Data Processing. Vocational data processing prepares students to enter the workforce as secretaries, data entry clerks, and computer operators in firms that use automated office and manufacturing equipment. Emphasis is usually on mastery of the specific hardware and software being studied rather than on understanding underlying principles and structures. For example, a trainee might complete a course on Lanier wordprocessing but be entirely unfamiliar with the operation of an IBM PC computer. Better designed courses will acquaint a student with several commonly used word processing systems so that the student can adjust quickly to whatever equipment the employer supplies. Data entry instruction and handling of peripheral equipment such as printers, tape drives, and key-to-disk machines may also be provided. More recently, vocational programs have used general purpose microcomputers running business applications such as Lotus 1-2-3 and DBase II. However, unless a student happens to secure a job at which identical hardware and software are provided, he or she can expect to retrain on different equipment with each new employer (Loop & Elman, 1982).

Student Tool Use. Some schools in the developed countries have recognized that students can use word processing, number manipulation, and data base management to improve their academic performance while still in school. These institutions include word processing in the English department and spread sheet applications in the math, science, and business departments, and may even add data base management into social studies and counseling. Many universities in the U.S. supply terminals for student tool use throughout the campus and some even wire their new dormitories for easy networking of student- owned microcomputers. But few elementary and secondary schools have well-equipped laboratories, tool use is not encouraged because it violates the funding guidelines under which equipment was purchased, the school lacks staff to keep the lab open, or the idea has simply not occurred to the administration.

Computer Programming. Computer programming may be defined as the communication activity by which the person specifies what the computer is to do in a manner which enables the computer system to perform the specified task (Bork, 1985a; Bozeman, 1985). Programming courses can begin, in rudimentary form, in elementary school and can continue through the doctoral level. Many universities, however, offer programming courses, especially at the undergraduate level, in diverse departments such as mathematics or engineering, rather than solely within a computer science department. This approach can be transitional in some cases (cf. Stanford University Bulletin, Courses and Degrees, 1985-1986, p. 324) and by design in others. Bork (1985a), for example, feels that the discipline- oriented nature of programming is evidence for maintaining its instruction within different departments under the condition that the instructors also understand computer systems.

Computer Literacy. The most popular instructional use of computers (reported by Becker, 1984) in all schools surveyed, was in familiarizing the students with the computer itself. Use of the microcomputer for this purpose was reported by 85 percent of the secondary schools and 64 percent of the elementary schools responding to the survey.

This latter finding actually indicates the "stage" at which many educational computer projects happen to be in their maturity cycle, by reflecting the schools' concern with having as many children as possible experience what a computer is and can do, but does not indicate how much drill and practice instructional software is actually used to teach children in subject matter areas.

Introductory courses generally reflect the first stage in the four-stage maturity cycle of computer use for instructional purposes. They are also the least instructionally satisfying in that they provide but limited instruction in computer hardware, languages, and certain applications within an interactive setting (Tashner, 1985), serving more to expose the students superficially to the technology than to offer a consistent, instructionally enhancing alternative to traditional classroom instruction. These types of introductory courses are frequently differentiated from computer literacy as described earlier in favor of the more precise term **computer awareness** (Bork, 1985a).

There also appears to have been a distinct shift (at least in the U.S.) from the earlier arguments for computer literacy which hinged on the equivalence of computer literacy to reading and math in the new information society to computer literacy for the enhanced job access. The shift has taken place in part because computers have failed to become major articles of consumption but are increasingly used in the workplace. Thus, computers do not play the same role as books and newspapers in people's lives but are tools of work. We will discuss the validity of computer literacy for job access in the next chapter.

Computers as a Means of Instruction

Federally funded U.S. projects to develop major blocks of instructional programs began in the late 50s and early 60s with the PLATO Project at University of Chicago (Easley, 1968), the TICCIT Project (Mitre Corp., 1979), and the Huntington Project SUNY Stonybrook (Dirks, 1975). Although such software inspired pioneers of the computer education movement, much of it was too expensive for daily use in the classroom and coverage of the curriculum was spotty at best. Teachers began to lament the lack of educational software to meet their needs and, in spite of massive increases in both quality and quantity of software available today, teachers still say there isn't enough.

The roots of the use of computers as a means of instruction are firmly planted in the United States as a result of the early cooperation involving the private sector (e.g. Control Data Corporation [CDC] and IBM), federal agencies (e.g. National Science Foundation [NSF]), and private foundations (e.g. Carnegie) with major universities such as Dartmouth, University of Illinois, and Stanford beginning in 1958 (Chambers and Sprecher, 1983). Through these collaborations, computer uses in education developed into its major program areas. At Dartmouth, John Kemeny and his associates developed BASIC, today the most popular language of personal computing (Curran and Curnow, 1983). At Stanford in 1963, Patrick Suppes and his colleagues presented some of the earliest CAI modules, essentially determining at that point the content areas, one of the major program areas, and the software application type which to this day prevail within the U.S. educational sector: mathematics and language arts, remedial programs, and drill and practice applications, respectively (Bork, 1985a; Taylor, 1980; Willis, Johnson and Dixon, 1983).

Drill and Practice. Most educational software remains of the drill and practice type (Bork, 1985a; Bramble & Mason, 1985; Burke, 1982; Chambers & Sprecher, 1983; Lathrop & Goodson, 1983; Mehan, 1985; Swartz, Shuller, & Chernow, 1984; Williams & Williams, 1985), especially popular as an instructional method within primary schools. At the secondary level, however, the principal use of computers is to teach programming, with "business applications" (spreadsheets and word processing) second, and drill and practice third. Becker (1987) reports on a 1985 national survey that, "More than 50 percent of the computer time for students in elementary schools involves computer-assisted instruction (CAI) with drill-and-practice or tutorial programs and only 12 percent of the time is spent writing computer programs. High school students, on the other hand, spend only 16 percent of their computer time on CAI but fully 50 percent in programming" (p. 150).

These two uses (i.e. drill and practice and programming) have also been shown by other surveys, both national (Tucker, 1983, cited in Mehan, 1985; Becker, 1987) and local (Miller, 1983; Boruta et al, 1983; Cohen, 1984, all cited in Mehan, 1985), to be the two most prevalent means of using computers with students in grades K-12. For those students who are actually using the computer within specific content areas, especially in math and language arts/reading, drill and practice software appears to reign supreme. Patterson (1983), for example, reports that of the 93 "favorite" educational software programs identified through a survey of 2000 computer-using teachers, 66 (71 percent) of the programs were identified for instructional use (the remainder being administrative uses), and nearly all conformed to the drill and practice model (in Mehan, 1985).

Furthermore, there is also a difference between the lower and higher grades in the role of computers in the curriculum: according to the Becker report, from kindergarten to the eighth grade, computers are used primarily for enrichment; they also play a mediation role during these years, but remediation is never more than 33 percent of all computer use. In the secondary grades, consistent with the programming and business application uses, computers become integral to class instruction (Becker, 1987, p. 150). And while computers are used in the lower grades to help in math and language (through drill and practice), in high school, the computer is used little in language arts and math.

Problem Solving Skills. Besides teaching programming as an end in itself, the other widely-held purpose for teaching programming to elementary and secondary students is to improve their problem-solving and logical thinking skills. Perhaps the foremost proponent of this argument has been Seymour Papert, mathematician and co-developer of LOGO, a programming language for children "of most ages and levels of academic performance [that enables them to learn] how to use the computer" (Papert, 1980).

Programming is generally and popularly seen to have several intellectual and creative benefits which accrue to the learner and thus warrant its study. Swartz, Shuller & Chernow (1984) summarize these benefits as "fostering procedural thinking, fostering thinking about thinking itself, [and] engaging children in active, creative learning." Much of the conventional wisdom regarding these benefits has not been substantiated by empirical research (Bork, 1985; Pea & Kurland, 1984), which in fact indicates that learning programming skills will not facilitate problem-solving skills in other situations (Suden and Rowe, 1985).

Papert sees LOGO as being able to change minds in fundamental ways due to its simplicity and ability to provide feedback and adapt to the individual (Dray and Menosky, 1983). LOGO's purpose is to enable the child to learn concepts usually associated with formal learning (i.e. within the school) in a manner which reflects their natural ("rooted in real life") learning style, and thus bridge that heretofore unassailable gap between those concepts within school which have been "easy" to learn (those closest to their life experiences) and those which have been "hard" (concepts not sufficiently within their life experiences, such as many within mathematics) (Papert, 1984).

The key to the learning experience which Papert advocates is free access to the computer by children such that "They can play with it without adults standing over their shoulders. They can take possession of it, rather than be possessed by it" (Papert, 1984, p. 21). Possession, however, is contingent upon the child programming the device (the well-known LOGO drawing implement, "turtle"), which in itself requires the child to describe in mathematical terms (by way of the keyboard and in fairly simple, straightforward human language) what the child wants the turtle to do.

The child learns programming through a process of discovery, much as we perceive the child to learn within his or her natural environment. Therefore, what the child programs the turtle to do is, at the beginning, not necessarily what the child actually desires to see on the screen. Through trial and error, the child eventually learns how to manipulate the turtle in order to achieve what he or she originally desires.

According to Papert, the child now has a fundamental understanding of some mathematical concepts which have been a consequence of the child's natural experience. This conceptual knowledge and the ability to manipulate it will now be transferable to the formal setting and be reflected in the child's greater understanding and ability to learn traditionally more difficult concepts such as those found within mathematics.

Not every educator agrees with Papert. For example, LOGO has been described by some CAI authors (e.g. Hudson, 1984) as an "idiosyncratic" program, one that "will allow the child to do a great deal of problem solving by means of manipulating text, processing lists of information and recursive programming [but is] not suitable for the highly structured learning that older children need to absorb. . ." (Hudson, 1984, pp. 7-8).

Tutorial and Diagnostic Systems. In contrast to drill and practice, tutorial and diagnostic systems are designed to *substitute for* rather than *supplement* some functions traditionally performed by the teacher. Tutorial software presents new material in an interactive mode (compare with books which present in static form) and may replace lecture or other teacher-lead classroom practices. The interactivity of such tutorials provides interest for the student and, when properly designed, keeps track of student comprehension and branches to remedial material should the student fail to grasp the salient concepts offered in the initial presentation. Computer-based tutorials, most commonly found for introductory high-school and college topics, free the instructor from the repetitive task of presenting introductory material to each new class, provide for more flexible scheduling (since each student works independently at a terminal or microcomputer at a time of his or her own choosing), and, in some cases, permit an institution to offer courses for which no resident human instructor is available.

The role of diagnostic computer systems in education is to analyze the student's mastery of the presented subject material and to prescribe remedial material appropriate to fill in the gaps in student knowledge. Remedial material may be computer-based or may be drawn from a list of print or other media-based instructional resources. A typical prescription, for example, might suggest that the student reread Chapter 7, section C of a well-known textbook and do exercises 5,6, and 9 in the accompanying workbook.

Recently developed "intelligent systems" draw on artificial intelligence (AI) methods from computer science to provide more sophisticated presentation, branching, and diagnosis. Here CAI or CAL is known as ICAL. AI researchers have concentrated on the development of principles to represent knowledge in an attempt to develop more computer understanding of natural language and natural language interface. Intelligent systems for tutoring and diagnosis borrow these principles to establish more response sensitivity between the user and the machine (Sleeman & Brown, 1982).

The assumption behind the integration of AI methods into CAL or CAI is that a machine can be built that will emulate the processes employed by a teacher when deciding how to help the student. Several experimental systems are currently being tested in U.S. schools, among them PIXIE (a diagnostic tool for identifying algebra errors) and DART (on Control Data's PLATO system).

Simulations and Games. Edwards et al (1978) define the simulation mode of the computer as one in which the real world is represented by a model which is believed to behave like some portion of the real world. The interaction may be either a straightforward simulation or a game. Interacting with a simulation/game, a student can typically test a strategy, experience the implication of his choices, and gain insight into the factors involved and their importance.

Simulations of field and laboratory science experiments were among the early developments in educational software. Published in 1971, The Huntington Simulation Programs were inexpensive packages consisting of a Student Workbook, Teacher's Guide, and Resource Handbook which contained background material and a listing, in Dartmouth BASIC, of the program to be run. Each program permits the student to try out different experimental variables by typing a numerical response on the keyboard. For example, the student may explore the effect of different chemical mixtures (in "LOCKEY, the Lock and Key Model of Enzyme Action"), apply different voltages (in "Charge, the Millikan Oil Drop Experiment"), or explore the consequences of different reproduction rates (in "POP, Three Models of Population Growth") (St. Univ. of New York, 1971). Thousands of simulation games have been written since by teachers, parents, and students themselves as well as professional programmers. Many have been implemented on every brand and size of computer. A few old stand-bys such as Lunar Lander, Classic Adventure and Lemonade Stand have been adapted from their original alpha-numeric output designed for teletype printers to include color graphics and sound produced by more modern computers.

The current state of the art in simulation uses an interactive computer program to control images stored on videodisc. While a few years ago this domain was almost exclusively explored by the military due to the high costs of production, some projects are now being developed in civilian academic settings. Sneider and Bennion (1983) in second language learning, for example, have created Montevidisco. Through this program, students can "spend a day" in a Mexican village "interacting" with Mexican native speakers and experimenting in a simulated way with the consequences of the linguistic choices they make when the program branches them into different situations. Students may find themselves, for example, getting a bus to a bullfight, reserving a hotel room, or purchasing vegetables in a market as a result of the response choices they select in their part of the dialogue.

According to Stevens (1983), videodisc technology in this domain of applications has at least two advantages over other media. First, videodiscs are faster than videotape, accessing their most distant points in five seconds as compared to several minutes for videotape. In addition, videodiscs offer "frame- perfect accuracy," beginning and ending each video segment at the exact points specified by the programmer. Videotape tends to overshoot the target location and begin at a slightly different frame on each access. A second advantage is that videodiscs bring "real," authentic chunks of everyday life into the classroom. In the area of second language instruction, for example, the authenticity of the material that can be incorporated into the instruction process is important; listening comprehension may be enhanced as students are offered access to a wide range of target culture varieties (with no pedagogical concessions such as simplified registers or slower rates) and students may gain direct insights into the target culture as the market, post office, train station scenes come "alive" in the classrooms. Unfortunately, videodisc-based simulations remain prohibitively expensive for most schools and videodisc technology may have to wait for an increase in budgets.

Networking

The term, networking, refers to several different concepts in educational computing. In one type of networking, hardware and software systems permit two or more central processors (computers) to share control of peripheral equipment such as storage. disks or printers. The other type of networking includes on the ways in which students and teachers use computers to communicate with each other, sometimes across great physical distances.

Local Area Networks. Local Area Networks (LANs), systems of computer hardware hooked together in a single room, building, or building complex are becoming more common in U.S. educational settings. A school computer lab, for example, may have a single hard disk which contains all the programs and data students will use in their school work on perhaps thirty microcomputers spaced on tables around one large room. Software in each microcomputer allows the student to copy a drill and practice program, simulation, or application into the microcomputer from the disk and run it. Printout can be directed to engineering for the last 15-20 years to extend this course to all secondary school students in the country in the 1985\86 academic year. The purpose is to provide them with some training in the field of computer science as part of their general education, to give some of them preprofessional training for future work in the computer science, and to acquaint the school staff with the potential of modern computers. Thus, the Soviet Union is focusing heavily on preparing an entire generation on computer literacy and computer skills, investing especially heavily in teacher training.

Countries like Mexico and India are preparing large computer literacy programs in their schools, stimulated by the autonomous introduction of computers in private schools and the fear that the informatization of the world economy requires a computer literate population (Carnoy & Loop, 1986).[5]

But there is not universal agreement with this rush to computers in schools. Two of the most important computer-producing nations -- Japan and Germany -- have moved relatively carefully on computer education, focusing primarily in training young people at the upper secondary level, with limited introduction of computers into lower secondary schools, and almost no computers in primary schools (only 2 percent of Japanese primary schools had computers in 1985). In part, the problem for Japan is one of the written language and its incorporation into computers and computer software. However, in both

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[5] Oteiza (1986) reports the following on computers in education in Latin America:

1) Small groups of specialists and developers are trying to move local authorities in order to generate minimal conditions to generalize the use of computers in education, while the majority of the initiatives, in this area, are made in the private sector, and many are commercially motivated.

2) Small - very small - scale experiments are taking place in most countries.

3) Reports of some small scale experiences are available.

4) Some countries, notably Brasil, Mexico, Colombia, and recently Venezuela, are implementing national plans in the area of computers in education.

5) Computers, and computer labs are available in many schools, starting with those in the most wealthy areas but, slowly reaching popular and even poor sectors. Access remains, however, extremely low and economically stratified.

6) Some Universities are offering computer oriented courses for teachers on-the-job-training.

7) National, regional and local technical meetings are being held. During 1985, in Chile, there were ten different national meetings.

8) A few individuals or study groups are developing software and some innovative uses of computers in education (Mexico, Brasil, Colombia, Argentina and Chile).

Computer networking is also being pressed into service in the private sector for nonformal education and informal discussion of educational issues. Individual subscribers to The Source (1986), CompuServe (1986), Dialcom (Loeb, 1982) and other public computer networks have set up ongoing conferences where they exchange ideas, opinions, and information about their own and their children's education.

International Trends in Computer Education

An international meeting held at Stanford University in March, 1986, under the joint auspices of Stanford and UNESCO, found that computers in education are being used worldwide for the purposes discussed above. Which of these uses dominates in any particular country depends largely on the nature of educational policy-making at a national or provincial level (much more so than in the typical district-level decision-making prevalent in the United States), on clarity of objectives, and on financial resources available. In most countries, the appearance of computers in education in the past has depended on the private sector (private schools and businesses), on experimental programs launched by the public sector (usually in response to the appearance of computers in private schools), or on national, centrally-planned, computer education projects, such as in France or the Soviet Union. Financial restrictions on educational spending has severely limited the use of computers in schools in most countries. Even in the developed countries, where resources are less of a problem, computer use in education has been limited primarily to the computers as an object of instruction (labor market-related uses) than as a means of instruction (raising academic performance).

Perhaps the most ambitious *national* program to date has been in France, where the French government launched an "informatique pour tous" policy in the early 1980s. That policy aimed to make France a highly computerized society by the end of the decade, with computers available in every French town, compulsory computer courses in secondary school beginning in 1985, and in the last years of primary school by 1986.

The growth in absolute numbers of personal computers for instructional use within the elementary and secondary schools in the United States during the past four years has been accelerating impressively and shows little sign of diminishing. In contrast to French-type strategy, however, the decisions on computers in schools in the U.S. are decentralized at the school district level -- there is no national plan. In 1981, for example, there were 31,000 personal computers in U.S. elementary and secondary schools; in 1983, there were 325,000. By June, 1984, 86 percent of the U.S. school districts had acquired 730,000 microcomputers, had acquired 1,275,000 by June, 1985, and were expected to acquire 4.9 million computers by 1990 (*Technological Horizons in Education Journal*, 1984; Yourdon, 1986:22).

The ratio of micros to students in the U.S., then, has changed within a two-year period from 1 computer to every 123 students, to 1 for every 34 students. Using 1985 levels under the same conditions as above, the theoretical amount of access by each student would be 15 minutes every one-and-one-half days, or approximately 33 hours per school year, an access period approaching, but still 21 percent shy, of the 40 hours of on-line work necessary for students to learn the essential "core programming" problem-solving skills indicated by Papert et al (1979) in their final report of the Brookline LOGO Project (Boyd, Douglas & Lebel, 1984).

The Soviet Union is building on a number of well-established pilot programs in secondary schools that have been teaching principles of computer science and computer engineering for the last 15-20 years to extend this course to all secondary school students in the country in the 1985\86 academic year. The purpose is to provide them with some training in the field of computer science as part of their general education, to give some of them preprofessional training for future work in the computer science, and to acquaint the school staff with the potential of modern computers. Thus, the Soviet Union is focusing heavily on preparing an entire generation on computer literacy and computer skills, investing especially heavily in teacher training.

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An international meeting held at Stanford University in March, 1986, under the joint auspices of Stanford and UNESCO, found that computers in education are being used worldwide for the purposes discussed above. Which of these uses dominates in any particular country depends largely on the nature of educational policy-making at a national or provincial level (much more so than in the typical district-level decision-making prevalent in the United States), on clarity of objectives, and on financial resources available. In most countries, the appearance of computers in education in the past has depended on the private sector (private schools and businesses), on experimental programs launched by the public sector (usually in response to the appearance of computers in private schools), or on national, centrally-planned, computer education projects, such as in France or the Soviet Union. Financial restrictions on educational spending has severely limited the use of computers in schools in most countries. Even in the developed countries, where resources are less of a problem, computer use in education has been limited primarily to the computers as an object of instruction (labor market-related uses) than as a means of instruction (raising academic performance).

Perhaps the most ambitious *national* program to date has been in France, where the French government launched an "informatique pour tous" policy in the early 1980s. That policy aimed to make France a highly computerized society by the end of the decade, with computers available in every French town, compulsory computer courses in secondary school beginning in 1985, and in the last years of primary school by 1986.

The growth in absolute numbers of personal computers for instructional use within the elementary and secondary schools in the United States during the past four years has been accelerating impressively and shows little sign of diminishing. In contrast to French-type strategy, however, the decisions on computers in schools in the U.S. are decentralized at the school district level -- there is no national plan. In 1981, for example, there were 31,000 personal computers in U.S. elementary and secondary schools; in 1983, there were 325,000. By June, 1984, 86 percent of the U.S. school districts had acquired 730,000 microcomputers, had acquired 1,275,000 by June, 1985, and were expected to acquire 4.9 million computers by 1990 (*Technological Horizons in Education Journal*, 1984; Yourdon, 1986:22).

The ratio of micros to students in the U.S., then, has changed within a two-year period from 1 computer to every 123 students, to 1 for every 34 students. Using 1985 levels under the same conditions as above, the theoretical amount of access by each student would be 15 minutes every one-and-one-half days, or approximately 33 hours per school year, an access period approaching, but still 21 percent shy, of the 40 hours of on-line work necessary for students to learn the essential "core programming" problem-solving skills indicated by Papert et al (1979) in their final report of the Brookline LOGO Project (Boyd, Douglas & Lebel, 1984).

The Soviet Union is building on a number of well-established pilot programs in secondary schools that have been teaching principles of computer science and computer primarily out of a fear of being left behind in a world entering the computer age. There is also a trend to equip primary schools in addition to secondary schools, and to use computers increasingly as a means of teaching computer literacy and as an aid in learning a range of non-programming, more general, academic subjects, especially mathematics.

Not only are computers concentrated in highly developed countries, but except in those countries where there are many computers for the student population (such as in the United States) computers used in education appear to be much less accessible to the poor and to women. Computers for education in developing countries are concentrated among those with relatively high incomes and attending private schools or public higher secondary schools and universities (generally a very small percentage of the school age population at those levels). This inequality of access threatens to make computer education highly elitist, limiting the development of better education to those already receiving the best and the most, and limiting the development of computer skills to a relatively elite group (not necessarily the most able to apply those skills).

Computer use is highly diversified. Most countries, with or without national policies, have computers being used principally in secondary education for vocational purposes; i.e., the preparation of technical and computer science skills. The tendency, however, is to extend computer use to teach "computer literacy" in the form of familiarity with pre-packaged software, such as word-processing and spread-sheets. Within levels of schooling, implementation varies among types of schools, but we know very little about the "quality" of implementation even when schools have hardware available and the computers are allegedly being used. We also do not know the minimum exposure necessary to assure a qualitative change in student learning. The research suggests that quality of implementation is closely related to teacher preparation, availability of software, and a well-articulated relationship between training, software and curricular objectives.

Consistent with this notion of the quality of implementation, we can define four *levels* of direct access -- from continuous access to a microcomputer and necessary software and instruction at one end of the spectrum to one time access at the other end. Specifically, the four levels are: (1) all variables fully supplied (ownership); (2) shortage of one or two variables; (3) one variable absent or all three in short supply; and (4) one-time access (See Appendix II-1 for a detailed analysis of these levels of access plus "indirect access" and "distance education"). The research suggests that even in the most developed computer education systems (in the highly industrialized countries), the vast majority of pupils have a level of access in which either proper instruction, adequate software, or time at the microcomputer are in short supply or one variable is totally absent.[4]

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[4] In addition to the amount of time available using computers, the access issue can also be viewed in terms of "cognitive access." Cognitive access is defined as the extent to which the available hardware and software is perceived as serving the cognitive needs and expectations of the potential users. It thus places an emphasis on the role of the learner, and the learner's interaction with that technology. An argument can be made that if computers are increasingly to become everyday features of our environment, and hence possess the potential to influence learning, it will not be sufficient simply to increase their numbers and make them available to students and teachers. The educational perspective must be appropriate, not only because this is essential to attain the potential

The actual distribution of computers within most countries' schools results in some schools and students receiving relatively high access, others some, and still others none. But very few countries have made empirical estimates of who gets access to computers in schools. Fortunately, recent studies in the United States have made such data available. These studies serve as a model of the kind of analysis that could be done for other countries. Their results indicate that even in a computer-rich country like the U.S., actual time access to computers by students in school is surprisingly limited, and level of access (which includes both in and out of school access) is still related to social class and gender.

Differential Access to Computers by Social Class, Ethnicity, and Gender in the U.S.

Earlier surveys in the U.S. showed an imbalance in programming instruction between non-poor schools and poor schools. Title I high schools, for example, experienced insignificant, almost static, growth in computer programming classes (7 percent), during the 1978-82 time period, while non-Title I high schools nearly doubled their growth (14 percent) (Anderson, Welch, and Harris, 1984). But the growth in recent years of computer purchases by schools have apparently brought computers in larger numbers to all schools. This has increased equality of access to computer courses and time actually spent using the computers, at least in school (Lockheed, 1985; Becker, 1987).

By 1985, nearly one-half of elementary and middle school students in the U.S. and about one-third of high school students made some use of computers in school (Becker, 1987). According to Becker's survey, a typical elementary school student *who had access* to computers at all used computers in school for about 35 minutes per week on average, but not necessarily every week. Many students never had access to computers at all. The typical high school student *who had access to computers at all* used computers for two hours per week. But even a smaller percentage of students in high school used computers. So while fewer students use computers in high school, they use them more intensively (p. 149). This means that even in the United States, where there are relatively many computers in schools, computer use in the classroom is very limited (Cuban, 1986).

In the early 1980s, most of the nation's poorest schools did not have a computer, while 67-75 percent of the most affluent schools had at least one (Christ-Whitzel, Dasho, and Beckum, 1984). This situation has changed as more and more schools bought computers and as Title I money from the federal government -- targeted at lower income populations -- was used by schools catering to those groups to purchase computers.

Recent views are mixed on the question of equal access to computing in US schools. The analysis of two recent surveys (Lockheed, 1985; Lepper and Daley, in preparation) indicate that there are no significant computer access differentials in schools among social class, ethnic, race, and gender groups. These results also suggest that with relatively large numbers of computers in the schools differential use among different social\gender groups *in school* is probably not significant, but that there are

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benefits, but also because a failure to identify this perspective will result in the ultimate failure of the technology and rejection by the educational community.

significant differences in using computers outside of school -- a differential use that has important implications for the kind of jobs these groups take in the labor market.

Lockheed's analysis of the 1984 National Assessment of Educational Progress data show that although only about 40-45 percent of students surveyed ever used a computer at school, student background factors (parental education, sex, ethnicity, region, district socio-economic status) were uncorrelated with computer use in school (Lockheed, 1985: 31-32). Neither, in general, did the type of course that different sex, ethnic, and social class students take (programming versus drill and practice, for example) differ significantly (except that higher social class boys were most likely to take programming courses in the eighth grade). Nevertheless, frequency of programming and computer use was correlated with parental education, presence of a home computer, and to some extent, race. Girls in the fourth grade tended to use the computer more than boys.

Becker's analysis confirms some of these results but contradicts others: he reports that boys "use computers more than girls do, although not everywhere and not in all respects" (1987:152). In the survey, girls constitute about one-half the students using the computer for word processing and half the students using computers overall -- this across all three grade levels. Enrollments in elective programming classes were also about one-half girls, with girls overrepresented in courses requiring higher levels of math. All this corroborates Lockheed's results. But Becker finds that, "Where computers are used either before or after school, boys outnumber girls 3 to 1. At the typical middle school, only 15 percent of the before- or after-school users are girls. Boys also dominate elective programming activities in elementary school and game playing in middle and high school. Girls dominate in high school word processing ..." (Becker, 1987: 152).

The Becker report does not differentiate students by social class, race, or ethnicity, but only by ability and "ability-level school classes". Since students in low-ability classes are much more likely to be minority students or of low social class (or both), while students in high-ability classes are likely to be higher social class and Anglo, the differences between low and high ability classes in the survey may give some indication of differential computer use by social class. Becker shows that students in high ability classes are much more likely to have computers in their homes. Low-ability classes in high school are much more likely to use computers for work in math and language arts (drill and practice) while students in high-ability classes are much more likely to use them for courses in computers and problem solving and for science (1987:158).[5]

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[5] Students who are designated as Limited English Proficient (LEP), especially if they are Hispanic, have also had less access to computers in schools, both quantitatively and qualitatively (Arias, 1984). Thus, drill and practice exercises for remedial purposes generally comprise their experience, while their fluent English-speaking counterparts, especially at more affluent schools, receive instruction in programming, tutorials, simulations, microworlds, and games (Shavelson et al, 1984).

There is evidence that students belonging to ethnic or racial minority groups, such as Asians, blacks, Hispanics, and Native Americans, have virtually no computer instruction experiences outside that in the school and home. Hess and Miura (1983) in surveying 23 summer computer camps found that 91 percent of the children enrolled were Caucasian while Asians comprised 5 percent, blacks 2.5 percent, Hispanics 1 percent, and Native Americans 0.5 percent (Miura and Hess, 1984).

A Stanford survey (Lepper and Daley, in preparation) also shows that higher social class boys are most likely to have a computer in their home. Boys reported spending more time using the computer, not only for programming per se, but also for word processing and game playing, even though they, too, report that there are no apparent gender differences in computer use in school. Similarly, higher social class students do more programming at home than lower social class students, and higher SES students report that they had done such programming longer than lower SES students, and spend more hours per week at the computer.[6] Again, no apparent SES differences appear in the frequency of computer use *in school* (high school, in this case). On the other hand, the range of school experiences does vary across SES group and there are also significant differences in the range of experiences between different ethnic groups -- especially Asians, at one extreme, and Hispanics, at the other (Loop, 1986).

In summary, there is considerable agreement that across-school differences of the amount of computer use are not significant by gender and social class, but that, within a school, the courses for which computers are used by different social class groups may be very different. Further, the outside of school use (i.e. home and recreational) is different both by gender and social class.

Lockheed also suggests that all these results may obscure the obvious: "First, although these NAEP data reveal few individual ethnic differences, the same data show that students in majority-minority schools -- those with 50 percent White students -- do have fewer computer resources. Majority-minority schools are less likely to use computers as part of their instructional program, to have computers for student use, to have computer courses, or to have "computer literate" teachers (Baratz, Goertz, and Anderson, 1985). Students in these schools, whatever their ethnicity, lack access to computer resources. Second, the NAEP data provide evidence regarding neither the quality -- as opposed to the quantity -- of computer resources available to students from different ethnic groups, nor the type of use made by students from different groups within ethnically integrated classrooms" (Lockheed, 1985: 52). [7]

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[6] Parents who have middle- and upper-class incomes take advantage of the opportunity to train their children in computer usage outside the school and home. Hess and Miura (1983), for example, surveyed 23 summer computer camps and found that 98 percent of the students who were enrolled were from upper- and middle-class families.

[7] Anderson et al (1983) reported that computers were used in 18 percent of "ghetto" schools surveyed but in 32 percent of "urban, rich" schools surveyed (cited in Lipkin, 1983). It is not just the number of computers, however, that differs between wealthy and poor schools, it is also the number within these schools that must be considered.

Affluent schools can afford ergonomically appropriate facilities, support materials, maintenance contracts, and larger numbers of computers. Poor schools cannot. Thus, within the same city, and within minutes from each other, a wealthy school may have a 1-to-39 ratio of computers to students, air-conditioned labs, a library of instructional software, and enough qualified instructors to satisfy learning demand, while its poor, predominantly black counterpart may have a 1-to-69 ratio, frequent multiple machine breakdowns, a 1-to-5 textbook-to-student ratio, and a 50 percent backlog of students

THREATS TO ACHIEVING THE POTENTIAL OF COMPUTERS IN EDUCATION

As in the case of other technologies, computers in education hold out the promise of preparing young people for a world that is itself becoming increasingly computerized and of improving general learning (we shall cover these topics in more detail in Chapter 3 and 4, below).

But there is a significant probability that computer technology will fail to realize its potential to improve education just as other technologies before it (Cuban, 1986). There appear to be four important barriers to overcome if the potential is to be achieved: (1) software development; (2) teacher training; (3) the low level of economic development in many countries (which not only limits financial resources available for microcomputers, but is characterized by structural conditions impeding computer education); and (4) within countries, equality of access to computers in schools among different social class groups and young men and women.

Software Development

Levin and Meister (1985) argue that the "generic failure of educational technologies has been due largely to a misplaced obsession with the hardware and neglect of the software, other resources, and instructional setting that are necessary to successful implementation" (p.9).

In the United States, it is widely recognized that the software available for educational computers is largely inappropriate and of low quality (Bork, 1984; Komoski, 1984). Levin and Meister identify the causes of this problem as follows:

> Unfortunately, CAI seems to be following a path similar to that of its predecessors. The software bottleneck associated with it seems to be caused by obstacles in the marketplace that tend to inhibit firms from undertaking large-scale, long-term investment projects. On the school side, the chief obstacles are the lack of clear adoption policies and the irregular funding base for software. On the industry side, the major obstacles are the lack of information about the market, the needs for large amounts of up-front capital in a situation of great uncertainty, resulting in a dearth of development capital for all but the least risky ventures (Levin and Meister, 1985, p. 53).

In non-English speaking developed countries and in most developing countries, the software problems are even more complex. Unlike other educational materials, software circulates internationally from its country of origin (generally one of the English-speaking countries). The use of imported products creates three kinds of problems: (1) the unsuitability of software for the curriculum being used; (2) linguistic problems for countries where English is not spoken; and (3) cultural problems in terms of the models inherent in the software.

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wanting to learn about computers due to a lack of qualified instructors (Kotlowitz, 1985).

As Hebenstreit (1984b) notes:

> Willingly or not, the educational software designed in a country carries with it, in many subtle ways, the social and moral values of the culture of that country and therefore the massive use of educational software designed in a foreign country will slowly but inevitably lead to a transformation and eventually to a decline of the originality and specificity of the national culture and traditions. This kind of difficulty is already well known regarding school books or books in general but it is much more difficult to analyze in the case of interactive educational software packages. (p. 16)

Most countries have therefore embarked on their own production, some on a national scale and some in the form of a "cottage industry," relying on teachers and on individuals outside the schools. For example, New Zealand has launched a national software effort targeted for secondary education. In almost all countries surveyed by UNESCO (1986), software is produced within the educational system by teachers, and, more rarely, by universities. In some of the developed countries, textbook publishers are entering into software production. Hungary and France have placed special emphasis on promoting software development by teachers. Yet, in general, educational software production is decentralized and crude, characterized by little quality control and subject to difficulties of portability because of lack of hardware standardization. In addition, few measures have been taken by educational planners and administrators regarding software distribution.

Thus, although projects such as this indicate that the countries now embarking on computer education may be able to avoid one mistake made in the U.S. -- that of having computer scientists and "hackers" develop educational software without consultation from teachers -- the general lack of teachers contributes to the magnitude of the problem.

Teacher Training

Few countries seem to have taken the necessary steps to prepare teachers for using computers, even when hardware is installed in schools. There is also little agreement on how to prepare teachers beyond short-term courses for practicing teachers -- courses of 6-15 days that merely help them understand how to use computers in the classroom. But the problems of implementing even this type of training are apparently very great. The countries most committed to computer training for teachers (Sweden, U.K., France, Australia, and Canada) have reached only about 25 percent of their teacher force. More typically, less than 5 percent of teachers have had such courses (2 percent in Latin America). Even though some countries have recently launched national teacher training programs (India, Chile, Korea, Cuba, and Mexico,) most are not willing to devote the resources necessary, focusing more on buying "visible" hardware. Longer training programs in computer science needed to prepare teachers for developing educational software are considered desirable by many experts in computer education, but these programs are necessarily expensive (although the pay-off to them in terms of developing software and training other teachers may also be large). The main drawback of such training is that many of the teachers who do best leave teaching to take computer programming jobs in industry.

The Impact of Underdevelopment

The contrast between childhood in an industrialized society which involves "a constant source of messages (in printed form or picture form) or signals (flashing lights, traffic lights, etc.)" (Hebenstreit, 1984.) and that in less industrialized environments leads to an assumption that the constraints of computer instruction--use of keyboards and interpretation of print and pictorial information--will be problematic for LDC children. Literature emanating from LDCs themselves, however, gives no specific indication that their students have any unique response to the *technology* itself. Individuals anywhere in the world who lack keyboarding skills must develop them in order to use a keyboard input device efficiently. There is no indication that it is more difficult for a five year old East African to learn to type than for a five year old Texan.

On the other hand, *cultural* incompatibility in language, symbolization, and reference to familiar items in the student's environment is an impediment regardless of the technological environment of the countries in question. For example, a German speaking child will have just as much trouble using software in Spanish as in Vietnamese irrespective of the fact that Spain may be considered more developed than Viet Nam. Likewise, the transition from Roman letters to Canji characters has been a difficult obstacle to the transfer of U.S. computer technology to Japan although both are technologically developed countries. This same obstacle is now an object of concern in the Arabic countries, not because they are underdeveloped, but because of the symbolic differences in language (Unesco, 1985).

The same logic can be applied to references to cultural items or behaviors made by text or pictures in software. If, for example, a CAI program designed in the United States used the symbol of the Liberty Bell to indicate a free choice was being given to the student, an Australian child might find the symbol nonsensical and difficult to remember. Thus Hebenstreit (1984) recommends that "different modes of use of computers in education should not simply be transferred to developing countries but should be analyzed and reappraised in the light of the context of each country" (p.15).

The impact of centralized educational policy is especially notable in LDCs. Oteiza (1986, p.6) points out that:

> In poor countries, where inequality is the norm, and the power of a few is much greater, and alternatives have to be created, political and economically oriented decisions are most important. The relative weight of small groups on agencies or governments is tremendous. This situation is complemented by an uneven distribution of information, education and, naturally, economic power. Any strategy to modify existing educational conditions has to take these kind of considerations into account, as well as the fact that educational systems are highly centralized.

"Conditions of dependency affect all Latin American countries and are reflected in the area of computers in education in many ways, " according to Oteiza (1986, p.5): regulation of the local computer market by foreign corporations and cultural alienation resulting from external software are important factors. In addition, the reductions in cost of equipment experienced in wealthier countries are attenuated by continued high costs of transportation and taxes in LDCs.

Finally, the generally low investment in education is a primary factor acting against employing such an expensive technology. As Marshall (1984) puts it: "The operational expenditure per student per year in a typical African country would purchase perhaps three blank floppy disks." Although Africa may represent an extreme case, costs per student- contact hour for direct computer access are still higher than many developing countries spend per student per WEEK.[8]

Differential Access Within Countries

Our review of access to computers among youth in the United States indicates that present patterns may limit access to computer professional jobs to higher social class, White (non-Hispanic) and Asian males. In part, this is an issue of choice; women and non-Asian minority males appear to be less "interested" in computer programming and motivated to get involved in it, especially outside of school. But this issue is related to the more limited access that the disadvantaged everywhere have to knowledge technology, whether it be printed materials or computers. If the disadvantaged (in many countries, these are the rural and marginal urban students in primary schools) tend to be denied such access, especially to the problem-solving, scientific applications of technology or the higher forms of applications to language arts, it is logical that they will have much greater difficulty gaining access to the professional and highly technical jobs associated with the production of new technology, as well as the directive jobs throughout the economy that rely on the collection and manipulation of information. Furthermore, if knowledge production and distribution become the key elements in future economic and social relations and the division of labor, the disadvantaged -- with limited access to computer technology at home and in schools -- may be in an even worse economic and social position than they are today. In this sense, computers will fall far short of their potential in developing skills and knowledge for the future, and could even exacerbate inequalities in many countries.

Of course, access to computers in school and their effectiveness in the classroom may not be very important if there is little relationship between computer education, learning, future labor market position of individuals, or the economic development prospects of a society as a whole. Thus, the discourse on computers has to be set into two contexts: the context of economic and social change and the context of educational impact. It is to these subjects we now turn.

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[8] The literature indicates that severe limitations to direct computing access also arise from the physical conditions surrounding computer installations even for the more robust microcomputers. In Nigeria, unreliable electrical supply interrupts computing activities at university-based facilities (Suraweera, 1983) and electricity may be completely absent in many rural areas throughout the developing nations. In tropical areas, high temperatures and high humidity may cause problems which are compounded by lack of spare parts and technicians to install them.

APPENDIX TO CHAPTER II

LEVELS OF DIRECT AND INDIRECT ACCESS TO COMPUTERS

The literature on computers in education--introspective accounts, classroom anecdotes, broad surveys, detailed "how-to- do-its" and effects research--warrants the creation of an explicit distinction between direct and indirect access. Direct access refers to the manipulation of computers by students while indirect access refers to benefit from another person's direct use of the computer (e.g. cost reduction of certain services, delivery of a service at a distance, and so on).

Direct access to computing by the student involves three components 1) presence of the computer system itself including hardware and software, 2) the number of hours of access available to the individual student per time period (e.g. per year)--from 100 percent of the time to a few minutes per year, and 3) the availability of knowledge about the computer system. This knowledge is more than just knowing how to use the computer at hand. It extends to knowledge about care, maintenance and expansion of the hardware, about availability and applicability of software, and about such consequences of computer use as time to accomplish the task or cost of hiring someone to do data entry.

We can distinguish four levels of direct access found in the home, school, or workplace:

Level 1: All variables fully supplied (ownership)

Level 2: Shortage of one or two variables

Level 3: One variable absent or all three in short supply

Level 4: One time access

Level 1 Access

The highest degree of access should bring to mind the rare and fortunate student who owns or has at his or her continuous disposal a microcomputer with educational software and peripheral equipment sufficient to his or her needs. Not only would such a student be able to put hands on hardware and software at any time, he or she would either 1) already know how to use both hardware and software with a high level of skill, or 2) have such knowledge available on demand from a teacher or other support person. Such an enviable situation exists only within very wealthy and extremely well-educated families, or in a few schools experimenting with "saturated"[9] computing environments. that is, an environment which provides continuous access to a computer for each student. (See, for example, Watson, 1986.)

The difficulty in achieving Level 1 access lies in the fact that, although money can provide equipment and (when available) software, it cannot always buy know-how or time to learn. Buying the hardware and software judged effective for one's needs is only the first step. One must also choose either to obtain the services of a person with the relevant knowledge or to invest the time in self-study of the books and manuals that accompany the products purchased. Knowledge is also the main ingredient offered by the infrastructure of user groups, magazines, conferences, and informal courses that have kept pace with the popularization of computing in the U.S. Even within the context of such an infrastructure, success is not guaranteed.

Level 1 access should not be inferred in all cases in which personal ownership of a computer is reported. In one study of 525 seventh and eighth graders, 68 percent of the students reported access to computers at home (Mandinach and Fisher, 1985). But these students, in many cases, did not know how to program their computers. In another study conducted in the same area, it was not uncommon for half of these young computer owners and their families to be unable to use their computers for anything except video games. (Wenn, 1985).

Level 1 access is most often found in an information-based industry (e.g. Apple Computer Corporation or the Bank of America) where a computer is a basic productivity tool and knowledgeable support personnel are provided by the company. However, few educational institutions consider themselves to be such "information-based industries."

Level 2 Access

On the second level we find one of the component factors in short supply. There may not be enough equipment to give all students access.

Elementary school decision-makers often choose to place computers in individual classrooms, while secondary school authorities typically opt to house most of their computing equipment in a computer lab. Schools that own just one or very few computers commonly make them available to teachers by some kind of sign-up procedure, or arrange to rotate transportable computers from classroom to classroom on a regular schedule (Knapp, 1985). In all of these cases, students rarely have more than a few minutes access per week.

In addition, student access may be time-limited even when there are quality hardware, software, and know-how at their school. This case exists when school policy

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[9] Saturated computer environments provide continuous access to a computer for each student, a large collection of software, and university trained assistants. Advocates of saturated direct computing access such as Papert (Papert and others, 1979) and Taub (1984) present strong arguments for accelerated learning and increased productivity that justify the cost.

requires that computer facilities be closed outside of regular school hours and class scheduling prohibits free access during class time.

Appropriate software may be in short supply due to lack of funds or because it has not yet been written. Although 1984 saw close to $2.5 billion in microcomputer software sales in the U.S. and about 10 percent of that was considered "educational" (Lefkowits, Bob, Infocorp. cited in Doyle, 1985), teachers still feel the lack of software (*IFG Policy Notes*, 1984).

In Level 2 access, any one of the components may be missing. We sometimes find high quality equipment and software but a lack of know-how. For example, many superbly equipped school computer laboratories in California's Silicon Valley sit idle because the faculty have no training or because they resist using the computers on the grounds that they were not involved in the implementation of computing at the school.

One might expect that the San Francisco Bay Area of California would be among the richest in experienced programming teachers. However, local researchers looking for junior high school study sites with "experienced teachers (those with three or more years of either programming or teaching computer science)" had difficulty finding schools. They report, "one criterion found to be problematic was teacher expertise. Few teachers had more than one or two years of classroom experience with programming. Therefore, teaching experience in other domains and some background in computing was accepted." (Mandinach and Fisher, 1985). Even when teachers are willing to invest their own time in learning to become proficient computer users they sometimes report that their schools have failed to provide them with the requisite manuals for their hardware. These same kinds of access problems also exist outside school settings. For example, even though a family member, friend, or associate has personal ownership or workplace access of the highest level as described above, the student may have to wait for an opportunity to use the equipment. Or, for example, students may have second level access for limited periods when there is a public access computing center or science-technology center in the neighborhood which promotes educational computing activities in a spirit of creativity and fun (Loop, Anton, and Zamora, 1983). Level 2 access also occurs in the home when families in the U.S. purchase expensive computing equipment for which they have no operating knowledge and either no time to invest in the acquisition or no source of that knowledge. Such equipment is likely to sit forgotten in a closet and be sold years later without ever being unwrapped.

Level 3 Access

On the third level, one of the components may be missing or all three components in extremely short supply. Lack of software would be the case in a school that is well equipped with hardware but has no software that the school is willing to allow the students to use. For example, most microcomputers are delivered with BASIC language and one or two games. If the school chooses not to promote BASIC programming, it will appear that there is "no software." It may be months or years after the computer has arrived until financial and/or deliberative processes result in the purchase of further software.

Hardware is lacking when a single computer is available to a whole school of 200 to 1,000 students, for most students will have extremely limited access. In such cases, the computer is often installed on a movable cart and wheeled from classroom to classroom every few days. Some schools put their one microcomputer in the school library with software that circulates like books; others isolate the computer in one department such as math and only a few students ever use it.

Level 3 lack of know-how is found in schools that have obtained hardware and software but have no trained staff. This also results in the computer being left in the hands of a few enthusiastic students and one or two adventurous teachers.

Level 4 Access

A fourth level is defined as one-time access, very similar to indirect access. Students who must travel extensively to visit a technology center or museum or students who only see the school district's computer one day a year fall into this category. Likewise, a child who occasionally visits at a parent's workplace but does not gain any substantive knowledge of computing would be included here.

Although both programming and some forms of computer literacy can be taught under Level 4 access conditions, this is analogous to teaching other "lab" sciences such as chemistry and biology without a laboratory.

INDIRECT ACCESS

Indirect access is benefit derived from another person's direct use of a computer. Positive outcomes associated with indirect access include: improved instruction of current students, gains in administrative efficiency, cost reduction for current services, expansion of current services, ability to handle more students in existing programs, and addition of distance education to serve remote students (Bowles, 1977).

CMI, Computer Managed Instruction

The most commonly cited example of indirect access in the U.S. and U.K. (Hebenstreit, 1984) is Computer Managed Instruction (CMI, or Computer Managed Learning [CML] or Computer Managed Teaching [CMT]). In CMI, a teacher uses a computer to enhance instructional delivery without requiring the student to know or learn anything about the operation or programming of a computer. For example, a teacher might keep a computerized grade book, produce or score tests using a computer, or write comments to parents using a word processor. This use of the computer by the teacher may augment time available for student-teacher interaction which is assumed to be of benefit to the student (Hebenstreit, 1984). Diagnostic and prescriptive software is available for teachers to use, enabling the teacher to match student test errors with remedial lessons in text or workbooks.

EDP, Educational Data Processing

Another type of indirect access is educational data processing (EDP). This category includes all administrative applications of computing within a school system, e.g. budgeting, payroll, data base management of student records, library and research applications, telecommunications among administrators, and so on. By providing speedy access to statistical data, increasing efficiency, and controlling costs, such application is assumed to produce indirect benefits that ripple down to the individual student. However, after reviewing reports from several developed countries, Hebenstreit (1984) views this process with some skepticism. Educational data processing exists at both a school level and a more centralized level of educational infrastructure including the region, state and country and national levels. Hebenstreit concludes:

> Since that time [1960s], comparatively little progress has been made and even today achievements in this field are limited and rarely go beyond the experimental stage. The introduction of micro- computers around 1975 has not significantly altered this state of affairs, and achievements in this new field are also restricted and remain largely experimental. (Hebenstreit, 1984, p. 5)

DISTANCE EDUCATION

Finally, there is indirect access that involves the creation, delivery, and feedback of educational material. An example of this is the TV Ontario Academy based in Ontario, Canada. The TV Ontario Academy is a correspondence school that makes use of television and newspapers to deliver the largest proportion of the instruction for its courses. Students register by mail from their homes and receive workbooks with computer-scorable answer sheets to be completed independently and returned by mail. On the basis of answer sheet scores, the computer system generates individualized response letters and prescriptions for further study. The authors report that computerization has permitted them to keep costs under control and to handle many more students than a manual system would permit. The individual student benefits from this type of computerization through increased numbers of courses offered, lower costs, and quicker response time. The only direct contact between student and computer is the answer sheet and the computer generated letter; thus such a use is classified as "indirect." (Daniel, 1982; Waniewicz, 1984). A similar correspondence school was also established in Japan in 1979 (Nishinosono, 1984).

Chapter III

THE COMPUTER REVOLUTION AND ITS IMPACT ON EMPLOYMENT AND SKILLS

A crucial argument for computer education is that using computers in school is necessary preparation for a new world of work. In that world, it is alleged, the ability to interact with computers is the key to better jobs and higher productivity. This argument can be divided into two parts: the first contends that a high fraction of future jobs will be associated with computer skills; the second claims that computers in schools are important to preparing people for those jobs. We will examine both of these claims in this section.

There is little disagreement that microelectronic technology will influence almost all countries' economic growth, employment, and wages. It appears to be doing this in two principal ways: first, by diffusing throughout the world, it contributes to changes in the conditions of industrial development [eventually, with advances in biotechnology, that form of new technology will also change agricultural development]; and second, by rapidly improving telecommunications and informatics, it accelerates the integration of every society into the world economy.

The main question regarding such technology, then, is not *whether* it will impact the way people live and work, but *how great* an impact it will have and what its *nature* will be. Are computers so changing production and consumption that societies also have to change their educational systems in order to prepare pupils for the computer society? Are the skills needed to work in the labor force changing in ways that require new kinds of learning in schools? How pervasive are these changes -- will most jobs be affected or just a small proportion?

VISIONS OF THE INFORMATION SOCIETY

Anthony Oettinger, Chairman of the Program on Information Resources Policy at Harvard, argues that information is a basic resource like materials and energy -- in the future, those who have more of it will tend to be materially better off, and those with less may be worse off: "By widening the range of possible social 'nervous systems' the continuing growth of information resources is upsetting the world order just as the Industrial Revolution upset it by widening the range of physical modes of production. Where this will lead is as hard to foretell as predicting today's world when the steam engine was invented. However, the timeless truth that knowledge is power once again needs reinterpretation because of newly abundant, varied, and versatile modes of gathering, storing, processing, transmitting, and exploiting information that contrast with ever scarcer and costlier materials and energy" (Oettinger, 1980, p. 191).

Yoneji Masuda, author of the Japanese *Plan for an Information Society*, published in 1971, believes that "The information society will be a new type of human society, completely different from the present industrial society ... *the production of information values and not material values will be the driving force* behind the formation and development of society ... In the information society the leading industries will be the *intellectual industries*, the core of which will be the knowledge industries" (Masuda, 1981, reproduced in Forester, 1985, p. 620-21; emphasis in original). Masuda goes on to predict a "Computopia," in which the voluntary community will be the most important subject of social activity, the voluntary civil society will maintain social order, and the political system will be participatory democracy.

Similar visions have been spelled out by Toeffler in *The Third Wave* (1980) and Naisbitt in *Megatrends* (1982). Such visions, were they to be realized, have important implications for the labor market and for education in both developed and developing countries. If the visions are correct predictions of the future, industrialized countries must plan for an economy in which their labor forces have to be trained for a whole new set of productive activities -- activities that are already underway, but still relatively underdeveloped compared to what will come. Those economies in the process of industrializing have to consider whether to "skip" the traditional industrialization phase and move immediately toward preparing to compete in the production of information. For most countries, this may imply a massive restructuring of education policies, focusing more on high level skills and less on those intermediate skills which may be replaced by automated, software driven machines (Rada, in Forester, 1985, pp. 571-589).

But these visions as accurate predictions of social and economic futures are hardly universally accepted. There are five principal critiques in the literature:

1. The very concept of the "information society" is questioned by many authors (see, for example, Marien, 1983, in Forester, 1985, pp. 648-660; Roszak, 1986). They argue that information itself has limited consumption appeal except as entertainment. Information as a producer input must ultimately be translated into the production of other production goods and consumer goods and services to have value. Therefore, the critics argue that characterizing future societies as "information" societies is misleading. Information in and of itself will not be the most important input in creating value and will not be a significantly important consumption good.

2. According to some critics, the visions of the computerized future are very uninformative regarding whether and how people will be employed and how the distribution of material output, information, and knowledge to produce information will be determined, if not by employment. Marien writes: "Unemployment caused by the automation of office work and other informational services may be extensive and, if not compensated by an equal number of new jobs in the information sector, could result in a labor force no longer dominated by information-related occupations. The major activity of society would then be some other occupation, or even involuntary idleness -- the lack of any occupation -- a condition that already characterizes some Third World nations" (1985, p. 650). Put another way, the visions are highly "technologically deterministic." They do not explain how policies necessary to assure the highly productive, democratic, and socially stable societies that will use the new technologies for human betterment rather than human oppression will come about. Implicitly they appear to assume that the technology itself is inherently democratic, socially stabilizing and equitable.

3. The visions usually assume that the new technology is inherently liberating. But, in practice, one major critique contends, the technology is being used largely for

increased control of production processes and increased centralization of that control (Shaiken, 1984).

4. The visions confuse information with knowledge and tend to make the two synonymous (Roszak, 1986). This leads inexorably and incorrectly (according to Roszak) to the identification of computer-related skills with overall creativity, learning, and understanding, when, in fact, there is no evidence that this is the case.

5. The visions ignore that much of the most advanced of the new microelectronic technology was and continues to be developed for military uses (Seigel and Markham, 1986; Noble, 1979); and therefore is not particularly oriented toward or designed for the solution of basic human problems, such as eliminating pollution, providing cheap and efficient transportation, or even developing more effective teaching and learning (more about this in Chapter 4). Much of the most advanced information consumption is by militaries around the world; they are also the most important sponsors of the development of information technology.

None of these criticisms, however, negates the contention that industrial society will tend to become increasingly information-oriented (even if not dominantly so) nor do they negate that computers will be increasingly important in the production process. Even if we were to regard the visionaries' view of future world society with a great deal of skepticism, we would have to come to terms with the potential impact of computers on jobs and the skills required in the labor market. To evaluate the relationship between computer skills and the changing job market requires turning to the growing literature on the job impact of high technology production and the application of high technology to production (automation).

MICROELECTRONICS AND CHANGING LABOR MARKETS

All evidence suggests that there has already been a significant impact of microelectronics on labor markets, especially in the developed countries (see, for example, Goldstein and Fraser, 1985). In order to evaluate the potential use of computers in computer-related skill formation or for computer literacy (preparation for interacting with computers primarily in a work setting), it is fundamental to understand what the nature of this impact has been. Has the tremendous increase of production of microelectronics and its application to producing other goods and services (automation) transformed the type of work that people do? Has microelectronics also changed the international division of labor? How do these changes square with the futurists' vision of the information society?

To answer these questions, we assess the data on how computers have changed labor markets internationally, what this implies for future skill requirements, and what the relationship is between these skill requirements and computer education in schools. This will help us assess whether one of the most widely used arguments for computers in schools makes sense -- that is, is there a rapid increase in demand for computer-related skills and are computers in schools important for developing those skills?

This discussion is set in the context of some obvious international realities. First, despite the rapid growth of microelectronic production and application in a few newly industrializing countries (NICs), such as Korea, Singapore, Hong Kong, Taiwan, Brazil, and Mexico -- production, consumption, and exports of computer technology are still extremely concentrated in the U.S., Japan, and Western Europe (see Kaplinsky, 1986).

Second, even among the developed economies, the adoption of new technology in the production of other goods appears to vary widely. Japan and Sweden, for example, have many more robots per employed worker than the U.S. or Germany (Edquist and Jacobsson, 1984). Third, we do not have much information about the degree of technological adoption or its effects in most countries. We can only speculate, based on the experiences of the developed countries and the limited experience of these NICs, what the pattern of labor market impact may be under varied economic development conditions, especially very significant differences in export orientation and different relations between business, labor, and government (see, for example, James, 1986; Carnoy, 1985). Finally, it is very difficult to predict how competition among developed countries, among the NICs, and between the NICs and the developed countries will change the world trade and investment system over the next ten to fifteen years, and what effect such changes will have on the diffusion of technology and the distribution of computer-associated goods and services.

Given these "realities" (or limitations), let us confront the issue of computers and jobs with two principal sets of questions:

1. How many and what kind of jobs are created by growth of the microelectronic industry and the application of microelectronics to the production of other goods and services? Do these jobs appear to require extensive programming skills or "computer literacy" (familiarity in the use of computers before being trained for the job)?

2. To what extent do and will computer-associated technologies penetrate different countries' economies? That is, can we predict how diffusion of the new technologies will take place and, therefore, how various countries may have to respond to computer-related jobs with computer education?

The Impact of Microelectronics on Computer-related Jobs

We divide the analysis of the generalizability (or not) of microelectronics' effect on the *number* of computer-related jobs into two parts: (a) the growth of jobs in the microelectronics industry; and (b) the impact on the number of computer-related jobs due to the increased *application* of computer technology -- information systems, office automation, and factory automation -- in other industries.

The Labor Force Impact of Microelectronic Industry Growth. Economists estimate that high technology industries (defined in varyingly broad terms -- see Rumberger and Levin, 1984) in the United States employed 2.5 million, 5.7 million, or 12.4 million Americans in 1982, out of a total of 92 million employees, and the projected increase of high technology employment between 1982 and 1995 is projected to account for anywhere from 3.4 percent to 16.5 percent of all new employment from 1982 to 1995. In the broadest definition of high technology, then, one of six new jobs will be in high tech industries.

But such a projection is misleading, since many jobs in high technology industries do not require computer skills or even computer literacy (for example, circuit board assemblers or quality controllers). Thus, taking high tech *occupations* as the basis of the projection -- where high tech occupations are defined as those requiring high technology skills -- yields a lower figure. Such jobs employed 3.2 percent of all civilian workers in 1982, and even with a 47 percent projected growth rate between 1982 and 1995 (compared with a 25 percent growth for total employment), high tech occupations represent only 6 percent of all new jobs in the U.S. -- 1.5 million in absolute terms (Rumberger and Levin, 1984, Table 3).

Taking yet a third approach, Goldstein and Fraser (1985) list 140 occupations employing 30 million workers in 1982 that were in some way involved with computers. They estimate the number of workers in those occupations who actually use computers (about 12 million) and the amount of training required for them to do their jobs.[10] Their "first group of occupations" -- those requiring extensive training and generally associated with the computer and microelectronics industry but not exclusively (for example, college teachers of computer science and programmers of numerically-controlled machine tools)-- amounts to only 0.6 percent of all workers and five percent of computer users in 1982 and, although growing rapidly in numbers, is projected to amount to only 1 percent of all workers in 1995. Their "second group" are primarily workers in the scientific and technical occupations who need to do some programming but can usually use software already available. But there are a number of non-high tech professionals also included here, such as accountants, auditors, and so forth. These occupations amounted to only six percent of all workers in 1982, and those who use computers in this group only amount to one percent of all workers and between five and ten percent of computer users.

Thus, both Rumberger and Levin's and Goldstein and Fraser's estimates show that even by 1995, the percentage of the U.S. labor force needing any extensive programming training probably will not exceed 3-4 percent of the labor force. The training of such workers is, nevertheless, critically important. The future of computer technology depends on the quality of the first group's training and much of the pay-off to more sophisticated applications depends on the second group's training. But the numbers cover only a small percentage of all computer users in the labor force.

The small absolute number of high technology jobs has significant implications for what most Americans will be doing in 1995. Whereas 8 out of 10 of the most rapidly growing occupations to 1995 in percentage terms are high tech jobs, those 8 will only produce 935 thousand jobs in the 1982-95 period. The 9 fastest-growing jobs in *absolute* terms are all service jobs, such as building custodian, office clerk, or secretary. Those kinds of jobs are projected to increase by 6 million in 1982-1995. Moreover, Rumberger and Levin (1984, Table 4), 7 of the 9 occupations require completed high school education (12 years) or less, whereas 6 of the 8 fast-growing high-tech-related jobs require some college or more. And the high absolute growth occupations have mean earnings that are 30 percent lower than the U.S. average, whereas the fast-growing high tech occupations average about 30 percent ***higher*** than average U.S. earnings. Indeed, new jobs in the American economy in the 1975-85 decade have been mostly *low wage* jobs, in sharp contrast to the 1947-1973 period, when new jobs were primarily higher than average wages (Bluestone and Harrison, 1987).

These figures suggest that high tech industries and high tech and high-skilled computer occupations will create a significant but not massive number of new jobs over

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[10] Goldstein and Fraser write:" In attempting to identify the computer-related education and training requirements for 140 occupations, one of the difficulties we found was that training methods differ considerably among members of a single occupation, and there is usually no standard method.... [as an example] computer programmers may have taken college courses in computer science departments, or short courses provided by computer manufacturers, or may have learned by self-study and experience" (p. 18).

the next decade, certainly not the number implied by its proponents. Even in the most optimistic projection of jobs in high tech industries or computer-related jobs, it appears that a majority of those jobs will not be in high-paying professional work, but rather in production or clerical work. The labor forces in developed countries will continue to expand largely in retail\wholesale trade and services -- the rate of growth depending primarily on the overall growth of the economy -- and jobs in these sectors will continue to be mostly relatively low skilled and low paying. The same statement can be made about labor market expansion in developed economies with "inflexible" labor markets, such as France, Italy, or Spain, where labor market expansion is in "non-official" jobs: even though manufacturing employment grows in the "underground" economy, most of these jobs are relatively low-skilled and low-paying, and concentrated in retail/wholesale trade and services.

In Third World economies, the employment impact of high tech production may be somewhat different. The active participation of several Asian NICs in the high tech boom of the last ten years as production centers for U.S., Japanese, and European companies, supplying components and even finished products for industrial country markets, attests to some economists' claim of high export elasticities for product groups affected by microelectronic technologies (James, 1985). For those countries, rapid high tech growth in industrial centers has contributed to rapid economic growth. Hong Kong, Taiwan, Singapore, and South Korea have profited from the farming out of developed country production to low labor cost, *high reliability* (quality control) Asian NICs [Kaplinsky (1986) reports that the electronics industry in S. Korea grew at a 35 percent annual rate in 1970-1982, but in 1977, this growth slowed to 18 percent, with production for domestic markets growing more rapidly than for exports (23 versus 14 percent)]. In addition, service industries, such as insurance companies, are contracting out data preparation (one insurance company has its keypunching done in the PRC and the data sent by satellite to the U.S.). Yet, for the moment, these are the most manual and repetitive tasks and correspond to a similar subcontracting of semiskilled tasks to "garage" assembly operation in the U.S. that employ illegal immigrant labor at below-subsistence wages. The employed in both the NICs and the garages are Third World women, and the work is unstable and dead end. Such assembly operations are also the most susceptible to business cycles in the industrial countries, where the products they assemble are used as inputs or sold directly. Therefore, the percentage of jobs in the NICs that can be classified as "high tech" jobs (requiring extensive computer training) is lower than in the developed-country, research and development centers.

This is not the only type of high tech production outside the industrialized countries. In countries such as Mexico, the Asian NICs, and the periphery of Europe (Spain, for example), final assembly operations take place for local consumption or for export to less-developed countries of the region (see Castells and Nadal, 1987, for information on Spain). Software development geared to imported or Japanese/U.S.-origin products produced locally is also found in a number of Third World countries, although on a limited scale.

Finally, some countries, such as Brazil and India, are "import-substituting", protecting the development of a local high tech industry through import controls on computer products but not exporting (see Evans, 1986; Desai, Khan, and Desai, 1986). This implies the development of a "total" industry and possibly new products; i.e., the *creation* of technology for local markets, including software, which implies that the state will have to provide similar support for the industry as is provided in the U.S., France, Sweden, Great Britain and Japan -- wherever there is an indigenous microelectronics sector. In Brazil, a country with a large business market for such products, as well as its own military production and a large state bureaucracy and education sector, there is an ample internal demand to sustain an indigenous, self-sufficient industry. But we observe that the growth of this type of industry is necessarily slower than microelectronics for export, and at best, will have the type of limited overall impact on employment that is predicted for the U.S. (unless Brazil and India can shift the know-how gained through domestic production into rapidly- growing sales for export).

Like many other assembly industries for reexport, electronics manufacturing employs almost entirely rather low- and semi-skilled, low-paid (female) workers. Thus, any developing country that can attract electronics assembly plants can increase industrial output, but will generally bring *new* workers into the labor force rather than taking up the slack of unemployed or underemployed males, and these workers will not require high technology, computer-related skills. With import-substitution production of high tech goods by branch plants of U.S. or Japanese producers (the Korean and Taiwanese cases), the effects on the labor force will be similar, except that more people will be employed because of the possible manufacture of components through subcontractors, and the greater employment of clerical help (linkage effects). Some sales and management personnel will be present, trained by the home office. And, in order to develop new products, we observe the employment of increasing numbers of engineers and technicians. Yet, these will generally not reach the levels of employment associated with research and development centers. Hence, we would not expect even the more successful microelectronics production economies such as S. Korea and Taiwan to require the relative numbers of computer-related high technology jobs as are required in the research and development centers such as the United States, Japan, or Great Britain (where the relative number of such jobs is certainly not massive). The relative impact of microelectronics production on the growth of overall employment in some NICs (those that concentrate a significant part of their microelectronics production in the export sector) is and will be greater than in the industrial countries because of the high demand in developed countries for these exported products and the relative size of these economies compared to the economies to which they export. But even with more rapid growth, the nature of the production of microelectronics in those economies will create a demand for relatively *fewer* jobs which require extensive training using computers. Higher skills in the labor force may make the labor force more attractive to foreign investment, but these "higher skills" may have little to do with computer-related training; rather, skills demanded may be much more related to accurate, high productivity assembly work, quality control, and good management. The more that a country is an export-appendage of industrial country economies, the more likely that the expansion of jobs in the high technology producing sector itself will involve relatively low-skilled female work.[11]

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[11] The skill mix in the production of microelectronics varies according to the amount of research and development employment in the sector's total employment (Gordon and Kimball, 1985). Highly educated labor is employed primarily in research and development (R&D) and in the marketing of microelectronic products. It is less prominent on the production side. Yet, despite this variation, there are generalizable aspects to the structure of the high technology sector. High tech industries in developed economies are more skill intensive than traditional manufacturing or the labor force as a whole. Labor in these industries is more highly educated but also more sexually stratified than labor in traditional manufacturing or the labor force as a whole. Women are concentrated in production and have relatively less education than women in the rest of the labor force and tend to do more repetitive, menial tasks, while men are concentrated in R&D and

There are also limits to the generalizability of the export model to the Third World as a whole. The two principal criteria for exports to developed country markets are low labor cost for semi-skilled labor and high quality control (Rada, 1985). Many developing countries meet the first criterion, but few meet the second. Thus, the diffusion of electronics production throughout the Third World will not necessarily be a rapid process. Further, much of the increase in demand for the NICs' electronics output will depend on the pace of introduction of the products into the developed countries, particularly if Third World countries pursue import-substitution, protectionist policies which prevent the importation of electronics from their competitors and promote the growth of their own high tech industries.

In summary, the growth of the electronics industry -- which should be an important source of computer-related jobs -- has been and could continue to be significant in some countries, but even there it does not appear to be creating the massive increase in such jobs often promised by the information society visionaries. Rather, the growth of microelectronics production creates many new jobs, often with new skills, but skills more likely to be associated with highly accurate manual work or with quality control, not computer-related technical skills.

The Effect of Microelectronics on Computer-related Skills in Other Industries. Although there is much debate about the contribution that microelectronics will make to the expansion of computer-related skills, the most controversial and speculative discussion focuses on the implications of informatics and robotics for computer-related employment in other industries.

The optimists contend that microelectronics, or computer technology, will not only create many new jobs as an industry, but that as its products are adopted in other industries, it will raise productivity, therefore raising profits and/or lowering costs, so that new demand will be created and hence new jobs (Lawrence, 1984). Many of these jobs will also be computer-related.

The pessimists, to the contrary, argue that jobs in the production of computer technology will only be a small proportion of jobs for many years to come, and that computer technology in the form of office automation and robotics may actually eliminate jobs in other industries more rapidly than higher productivity can create new jobs. So whereas remaining jobs in manufacturing, banking, insurance, and many forms of office work will be increasingly computer-related, their number will increase slowly.

The literature on the number of jobs created and eliminated by computer automation is extensive (see Kaplinsky, 1986), and it is not necessary to review it here. In general, it appear that computer automation itself (as opposed to the production of computer products) tends to be job-displacing (Katsoulakos, 1986; Kaplinsky, 1986). But more important for our purposes is whether the automation process also tends to raise the

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sales and have relatively more education and more "creative," responsible work than men in the rest of the labor force. This is also true in developing countries. The more production-oriented is the industry in a particular country, the lower the skill level and education required and the higher the fraction of women in the sector.

level of skills[12] required in production of goods and services and whether changes in the skills required are associated with the need for computer-related preparation in schools.

What will office automation and robotics do to the skills required in industry and the service and trade sectors? In the optimistic view, not only will many new jobs and new kinds of jobs be created by the growth of high technology, but increased skills will be required -- many related to computers -- and there will be less skill polarization. In the pessimistic view, new technology will result in a general deskilling even as a small percentage of high-skilled jobs grows, and this will lead to an increasing polarization of the labor force, nationally and internationally.

As for the effects of robotics, studies suggest that semiskilled production jobs -- operatives, assemblers, welders, and painters -- will be replaced with semiskilled maintenance and clerical jobs -- robot technicians, secretaries, and clericals. Thus, robotics will eliminate more jobs than it creates, but will not change the general skill level of those remaining.[13]

As regards office automation, a recent study of the insurance industry (Baran, 1985) suggests that the introduction of high technology eliminates the lowest skilled jobs, upgrades some semiskilled clerical and secretarial jobs connected with the operation of the equipment, and also tends to eliminate many lower and middle management jobs. It is precisely those lower and middle management jobs that provided upward mobility in the industry for women. One of the effects of office automation, then, may be to upgrade women into dead-end , relatively high-skilled and relatively low-paying clerical and secretarial work. An international comparison of banking done for the OECD (Bertrand and Noyelle, 1986) shows that in those countries such as France where it is very difficult to eliminate jobs through automation (because of legal protections for employees), much more reskilling takes place for existing employees than in countries such as the U.S., where some employees are reskilled but many are let go and new employees are hired to do specific tasks that did not exist before.

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[12] When we use the term "skills, I am referring to the type of work employees <u>do</u> on the job than any productive capacities they bring to the job. The skill level of a job is not an easily agreed-upon concept -- it can refer to the responsibility, stress, or initiative associated with it, the amount of time it takes to learn specific tasks, the wage rate (as a proxy for productivity), and so forth (see Spenner, 1985). When we refer to skill, we mean primarily a combination of responsibility, variety of tasks, training time, and wage rates. Obviously, there is a high correlation between employees' education levels and the "skills" required in their jobs. This is particularly true in high tech industries, where formal education is an important criterion for entry into higher paid, more responsible jobs.

[13] Shaiken (1984) provides a detailed analysis of the effect of robotics, numerical control, and computer-assisted manufacturing (CAM) on workers on the shop floor. His conclusions are that skilled workers are not necessarily deskilled, but that they are effectively prevented from fully applying their skills to the new computerized systems. Management is using the new technology to exert increased control over the production process even though this may not be the most efficient way to utilize existing skills. According to Shaiken, in practice, new jobs are created (programmers; computer designers, etc.) which are used in part to separate existing skilled workers from control over the new, computerized production process.

To sum up the conflicting evidence on the skill effects of high tech expansion: Case studies of individual industries show a tendency toward deskilling, but studies of overall deskilling/reskilling suggest that in recent years, the tendency is for skill levels in industrialized economies to increase (Spenner, 1985). Since, in addition, real wages and productivity have risen in most industrial countries over the past 15 years (the U.S. is a notable exception, but, on the other hand, U.S. employment has risen much more rapidly than in Europe and Japan), we have to assume that productivity and average skills are rising, at least outside the United States. The data on skill mix, combined with the overall projections of future job growth we discussed earlier, suggest that the continued growth of the service and trade sectors in the world economy relative to manufacturing will produce many more low-skilled jobs than the growth of high tech will produce high-skilled jobs. The expansion of the high technology industry itself, while much more high-skill intensive than traditional manufacturing or trade and services, still employs more semiskilled workers than professionals and technicians (Gordon and Kimball, 1985a; 1985b). Simultaneously, the introduction of high technology in production and services throughout the economy (including high tech industries themselves) tends to reskill labor rather than deskill it. So the role of high technology may be to upgrade skills within an overall trend in economies where the large majority of new jobs requires relatively simple skills.

All this suggests that the adoption of new technology itself may not cause a net decline in employment in industrial countries, and that the number of computer-related jobs associated with those that are automated and with microelectronics production itself will increase as automation occurs and economies expand.

Likewise, robotics and automation will increase computer-related employment in developing countries directly because the production of computers, microcomputers, programmable machines, and robots will undoubtedly take place partly in those countries because of their lower labor costs. At the same time, however, automation and robotics may cost the developing world jobs. Labor-saving technology may eventually become so intensively used as to make labor a much smaller component of the total cost of manufactured goods whose production is gradually being transferred to the low labor-cost economies (Rada, 1985, shows that the more automated production, the less of a comparative advantage Third World countries have). The manufacture of steel, heavy equipment and machines, and even textiles could become viable and competitive again in industrial countries. Developing countries -- to remain or become competitive in exporting those goods -- will be forced to manufacture them using similar, highly automated processes. This will increase the number of computer-related jobs in developing countries, even though the growth of such jobs -- as in the developed countries -- may be slower than envisaged because of the impact of automation itself on the total number of jobs.

Looked at a completely different way, Goldstein and Fraser (1985) estimate that 30 percent of all civilian workers in the United States are in occupations in which some workers use computers, and less than one-half of them -- one in eight workers -- *now* do so (in 1982). This number and percentage appears to be increasing but it is unclear whether the percentage of computer-using workers requiring higher levels of computer training is increasing. Goldstein and Fraser do not estimate whether the average computer skills required in the part of the U.S. labor force that does work with computers is rising or falling. They do estimate, however, that only about 10 percent of those who now work with computers need programming skills (of various levels, whereas

90 percent require training in operating computers with software already available. Thus, the overall computer skill level associated with operating computers is considerably lower than usually assumed (although other skills associated with some of these jobs may be much greater). "This widespread use of a new technology with relatively little special training reflects the success of the computer industry in making the equipment and software 'user friendly'" (Goldstein and Fraser, 1985: 22).

What is the Relation Between Computer-Related Jobs and the Need for Computer Education? The evidence suggests that computers will be used to automate the production of goods and services worldwide and that the number of computer-associated jobs will increase (although the absolute and relative number of these jobs may remain small in most countries of the world for a long time). At the same time, data on the growth of "high-tech occupations" -- those that are associated with computer programming and technical skills -- suggest that the number of jobs requiring computer skills even in the highly developed countries is not very great compared to the job market as a whole. To reconcile these apparently conflicting positions, we have to ask how much previous computer training all the jobs associated with computer automation require.

It is commonly assumed that previous training on computers will be (or already is) a *necessity* for the job market: "It is simply an article of faith that every child must know something about computers in order to survive in life -- and those who learn about it early will be at an advantage over those who don't ... by 1990, 60 percent of all jobs in the United States will require computer literacy, and by the year 2000, 80 percent of all jobs will require computer literacy. Assuming that this is true, it is obviously important to teach computer literacy to children as one of their fundamental skills" (Yourdon. 1986).

In one of the only studies available that assesses the computer-training requirements of jobs in the labor market, Goldstein and Fraser (1985) suggest, as we have already shown, that relatively few of the large number of jobs and workers in those jobs using computers require programming skills.

But their study also suggests that in the U.S., most people who get trained to use computers, do not do so in schools but rather on the job. They found that, except for the 2-3 percent of workers who need extensive computer-related training and those computer professionals who learn programming as part of their university training, most people "have been trained on the job by their employers or sent by them for training to equipment vendors, professional associations, or schools" (p. 34). This may have been a matter of expediency in an era where incumbents of jobs had to be trained quickly, but even so, Goldstein and Fraser argue that, in the future, there are substantial advantages to continue on-the-job training as the principal form of preparing employees for those jobs that do not require extensive programming skills.

> For occupations which do not do programming or word processing and are not involved in maintenance of computer and electronic equipment (that is the great majority of workers who operate computers, using a keyboard, as a tool in their work), the computer skills can be learned quickly. Since a variety of equipment and software are in use, there are advantages to learning on the equipment they will be using in their jobs and the specific tasks they will be doing. This favors on-the-job training, the principal mode of learning now followed. As long as computer use continues to grow rapidly and new models continue to come out, on-the-job training will continue to be a major way in which skills are

> learned. Experience and familiarity with computers undoubtedly help in this learning process -- whether the experience is in other jobs, or in computer-assisted instruction in school subjects, or hands-on experience in a computer-literacy course. But even for people without experience the learning is so rapid that experiences of the kind mentioned do not speed up the learning significantly. Employers who have instituted programs of on-the-job training will probably assume that all new workers have to go through the program, whether or not they have some of these kinds of computer experience (Goldstein and Fraser, 1985: 34).

These results raise questions not only about training in schools for more general kinds of computer jobs, but about computer education for "computer literacy." As we suggested in the previous chapter, the argument for computer literacy has gradually shifted from one which equated simple computer skills with math and reading skills (in the context of the new information society) to one which focused on building a foundation for changing job skills. Yet, the Goldstein and Fraser study, as well as the Rumberger-Levin estimates, suggest that computer literacy is not an important requirement for a very high fraction of present or future jobs. Indeed, the tendency toward increasingly use-friendly software could make such computer literacy training even less relevant in the future than it is now.

Such findings and projections may seem surprising, but the data behind them are logical and convincing: the overwhelming majority of workers involved with computer use can learn the skills required quickly with brief formal and informal training by employers, and

> ... that no large burden will be imposed on the educational system to prepare students for work in the computer age. The burden on the educational system will be centered on a few sectors: departments of electrical and electronic engineering (and related basic sciences) and departments of computer science in the colleges; and the teaching of such subjects as electronics, typing skills, and business and accounting practices in vocational and technical schools ... (Goldstein and Fraser, 1985: 38).

From the standpoint of developing countries, this may be good news or bad news. The good news is that they do not have to make an enormous investment in educational computers in order to participate in producing or using computers in the labor force. Instead, they can focus on improving the quality of education using whatever technology does that best and investing in computer programming and engineering training at the secondary and university levels. The bad news is that simply developing a computer literate population will not guarantee entry into the international microelectronic sweepstakes. Investment in computers and microelectronic production, including the training of the labor force to use computers for a variety of specialized tasks is far more important.

ACCESS TO COMPUTER JOBS AND THE IMPLICATIONS FOR COMPUTER EDUCATION

Stratification by gender and race is already evident in the relatively new realm of computer-related jobs within the U.S. (Kotlowitz, 1985; Carnoy, 1985; Strober and Arnold, 1985). Women, blacks and Hispanics are all under-represented in the high-technology job categories. According to one estimate, although women have been making significant strides in computer- related jobs, they still make up only 30 percent of its workforce, while black comprise only 5.3 percent, and hispanics 1.8 percent (Kotlowitz, 1985). The kinds of computer jobs women and minority males hold are also very different from those held by white males: the latter tend to occupy most of the jobs requiring programming skills, while women and minorities get 'what Goldstein and Fraser identify as those computer jobs requiring only a few hours to a few weeks of on-the-job training (Carnoy, 1985). Strober and Arnold (1985) show significant gender discrimination in computer-related technical occupations.

In a study of Silicon Valley's labor market, Carnoy (1985) shows that whereas 68 percent of the white (anglo) male employees in the electronics industry in 1979 were professionals or managers/administrators, only 29 percent of white (anglo) women were in those occupational categories. Whereas 15 percent of the labor force in electronic manufacturing was hispanic (male and female) a much smaller percentage was professionals or managers.

Furthermore, increases by some minority groups within important areas of the computer-related jobs category is diminishing rather than increasing. There were actually fewer black and Hispanic computer systems analysts in 1984, for example, than in 1983, as their percentage representation dropped from 8.9 to 7.1 percent. But during this same period, women computer systems analysts increased from 27.8 to 30 percent (Kotlowitz, 1985).

These figures should not be surprising, and we would expect similar results in almost every country except that social class may replace "minority group" as a stratification variable. The point is that the professional jobs associated with high technology or computers go to those who are not only interested in computers and programming but go to university. With relatively fewer disadvantaged group (or lower social class) university students as a percentage of the disadvantaged group's university age cohort, there will be less opportunity for any professional jobs. In addition, women and disadvantaged groups are less likely to major in engineering and computer science for various reasons. Disadvantaged males, for example, are less likely to do well in math or have computers in their homes (as we discussed above, in Chapter 2).

Would increased computer education in secondary and primary school result in greater computer-related job opportunities for the disadvantaged or women? On the one hand, we have seen that since poorer schools tend to get computers last, the more computers in the schools, the more likely the disadvantaged will get access to them and can get interested in programming. We will also show in the next chapter that the disadvantaged tend, in the U.S., to show greater gains in learning as a result of CAI interventions than those who are already doing relatively well in school. On the other hand, if Goldstein and Fraser are correct and if Becker's (1987) argument that higher performing high school students are the ones taking the problem-solving-oriented programming courses, the principal way that the disadvantaged will get access to the good computer jobs will be by doing better in general school subjects -- especially math -- early on and then getting into the enriched computer programming courses and into universities where they can major in some form of computer science or engineering. Whereas CAI may help in achieving such better general performance for the disadvantaged, there are other technologies that could also be used to achieve such an objective. It is a different objective than simply getting more minorities or lower social class pupils interested in computers or computer literate.

Chapter IV

COGNITIVE AND MOTIVATIONAL OUTCOMES OF COMPUTER-MEDIATED LEARNING

In Asimov's 1957 collection of short stories about the future, *Nine Tomorrows*, three of the "tomorrows" prefigured the impacts of intelligent machine on the acquisition, organization and use of knowledge. One story, "Profession," envisions a future in which youth, on an appointed "Day of Education," are *taped* with the full body of available knowledge and expertise in their assigned professions. While pioneers of the use of computers in education had less spectacular expectations for the new technology, they predicted dramatic improvements in the amount of learning, the pace of learning and the overall comfort and convenience of the educational process. Early research on the impacts of computers in learning contexts were primarily evaluations of experimental applications. These studies often reported on very narrow and domain-specific outcomes. The basic question was in the form : "Is it possible for task X to be executed using a form of computer mediation Y, rather than by traditional method Z." The more sophisticated of these studies employed research designs in the tradition of psychological experimentation, with measures of effect parameters taken before and after the computer experiment and/or comparison measures taken on similar subjects not subject to the intervention. Most reviews of the field draw primarily on the large body of these studies carried out primarily on applications in computer-assisted instruction. With the rapid spread of computer technology, however, educational effects are increasingly seen as society-wide rather than subject or site-specific. Recent studies have employed a wide range of social science research methods including survey and ethnographic approaches, and have given some attention to implementation features and process factors which may explain observed effects.

In the present chapter we examine the nature of various cognitive and motivational outcomes of the use of computers in learning, review the main body of studies on such effects, and discuss the implications of these early findings for long-range impacts.

THE COGNITIVE IMPACTS OF COMPUTERS

Modern wizards of the computer age have dubbed the invention "wheels for the mind." Research on *cognitive* impacts addresses the effects of computers both on what students think (educational content), and on how students think (intellectual competence). In the former case, studies focus on relative advantages of computers in the delivery on instruction in traditional subject areas. Effect measures are usually standard subject area achievement examinations. In the latter, researchers have been primarily concerned with postulated side-effects of the use of computers for programming on the reasoning skills of students. In this category of studies, impact measures tend to vary from study to study, and software applications are more the objects of learning rather than media of instruction.

Computers For Learning: Effects of Computer-Based Instruction

Twenty years have passed since the *Stanford Project* developed some of the earliest computer programs for use in American classrooms (Suppes and Morningstar, 1969). This project developed, implemented and tested prototype software for *computer-assisted instruction* and is largely responsible for the institutionalization of evaluation procedures in this field. To date, most educational software authoring is of CAI materials and the vast majority of evaluations are studies of either: (1) CAI *drill-and-practice applications* in which the computer supplements classroom lessons with practice exercises which "drill" the student in the basics; or (2) CAI *tutorial applications* in which the software is designed to present the full lesson. Computer *simulation software* was seldom used in CAI applications until the introduction of powerful microcomputers into the classroom in the early-eighties, but several evaluations have been carried out at the secondary and college levels. Intelligent tutoring software -- which allows students natural language interaction and control of the computer-mediated instructional process -- is increasingly available, but there exists few evaluations of its effectiveness.

Along side CAI applications, designed primarily to help students learn, has developed software for *computer-managed instruction* (CMI) which helps the teacher teach. These applications include computer aids for record-keeping, grading, and individualized guidance and regulation of student work. As computer use became increasingly commonplace several types of general purpose applications came to be used in education to assist student learning. These applications can be distinguished from classical CAI in that while then are employed a learning tools or to provide illustrative material, they are not usually designed for instructional delivery. Kulik, Kulik & Bangert-Drowns (1985) suggests that simulation, programming and problem solving software, for example, often serves this kind of auxiliary function, and, for analytic purposes classifies programs in which they are employed as *computer-enriched instruction* (CEI). As defined, CAI, CMI, and CEI have in common the purpose of supporting the delivery and learning of traditional curricula material. This discussion will refer to all three as categories of computer-based instruction (CBI). Other reviewers use the term computer-based education (CBE). Early reviews of the cognitive effects of computer-based instruction have typically included studies of CMI and CEI effects often without distinction from studies of CAI. We see CMI as having indirect rather than direct effects on the learner. The extent of computer use in CEI is often vaguely defined. The present treatment thus focuses on CAI effects and introduces CMI and CEI data primarily by way of comparison with findings regarding CAI.

Over 200 primary evaluations of the effectiveness if computer applications in formal education have been carried out. Most of these studies occurred during the seventies in the midst of considerable debate over the wisdom of computer-mediated learning. U.S. evaluations account for the majority of these studies, though important studies have been carried out in the United Kingdom and Canada, and a some research findings have been reported from studies in the Federal Republic of Germany, Australia, New Zealand, South Africa and France.

These studies are cited in Kulik, Kulik and Bangert-Drowns (1985) and Bangert-Drowns, Kulik and Kulik (1985). As far as we can see from the reported results, they are not systematically different from the results in the U.S. Two recent German meta-analyses of a large number of micro-studies of CAI reported at the stanford/UNESCO conference in March, 1986, show no significant differences compared to traditional teaching methods, whereas another analysis shows moderately high differences (see Lehman, Jurgen and Ronald Lauterbach, "The influence of Computers in schools on Knowledge and Attitudes" Institute for Science Education, Kiel University (mimeo)).

As with most topics of social scientific investigation, efforts to review the primary data range from those which are essentially "critical" and qualitative (e.g. Grabe, 1985) to those which emphasize quantitative summary of evaluation findings (e.g. Kulik, 1983). Quantitative treatments form the bulk of these reviews. Earlier studies tend to provide narrative accounts and assessment of individual evaluations, along with box-score summaries of their findings -- whether positive, negative or ambiguous (Edwards, Norton, Taylor, Weiss & Dusseldorp, 1975; Jamison, Suppes & Wells, 1974; Orlansky & String, 1979; Visonhaler & Bass, 1972)

Most recent reviews take a meta-analytic approach (Glass, 1976; Glass, McGaw & Smith, 1981) employing statistical tools and criteria in summarizing a variety of findings from the growing body of primary studies (Bangert-Drowns, Kulik & Kulik, 1985; Burns & Bozeman, 1981; Hartley, 1978; Kulik, Bangert & Williams, 1983; Kulik & Cohen, 1980; Kulik & Kulik, 1986; Kulik, Kulik & Bangert-Drowns, 1985; Niemiec & Walberg, 1985; Wise & Okey, 1983). Conclusions from meta-analytic reviews are generally regarded as more reliable than conclusions based on box-score results: first, because more objective criteria are used to locate and include primary studies; second, they provide estimates of the magnitude of discovered effects which are both more precise and less subject to reviewer distortion and bias; and third, available statistical techniques allow the researcher to systematically include and take into account many pieces of information about the nature of each study and its outcomes. Even so, recent critical examination of the CAI effects data (Clark, 1985) has raised methodological questions which cast doubt on the validity of generally accepted conclusions from meta-analysis in this field.

CAI Achievement Effects

Performance on standard achievement examinations is the most commonly measured outcome in experimental and quasi-experimental studies of CBI. Meta-analytic reviews have focused on the magnitude of the difference between achievement scores of CBI groups and "control" groups exposed to traditional instructional methods. For the purpose of cross-study comparison this *Effect Size* (ES) has been defined as the difference between the mean scores of the two groups divided by the standard deviation of scores in the non-experimental or "control" group. This index of effect, which represents change in terms of standard deviations, has well understood properties which are independent of the original units of effect employed. We can, for example, employ z-score tables to interpret ES values in terms of percentages of the area under a standard normal population curve. Thus, from an ES of 1 we can infer that the average student in the experimental group would out perform 84% of students in normal classes, and from an ES of 0, that the average student in the experimental group would out perform 50% of students in normal classes, that is, exactly the same as the average student in traditional classes, and so forth.

The most rigorous meta-analytic studies of CBI effectiveness have been conducted by James Kulik and his colleagues at the University of Michigan (Kulik, Kulik & Bangert-Drowns, 1985; Bangert-Drowns, Kulik & Kulik, 1985; Kulik & Kulik, 1986). In the case of CAI these reviews report reliable modest positive effects of CAI at all levels of formal education. K,K, and B-D (1985) report an average effect size of .47 from analysis of 28 studies at the elementary level; Bangert-Drowns, Kulik & Kulik (1985) found an ES of .36 using 17 studies in secondary schools; and Kulik & Kulik (in press) report and ES of .26 from 58 studies in colleges and universities. The strongest effect of .47 of a standard deviation means that the average CAI student in elementary school out-performs 68% of his fellow students taught in similar courses without CAI materials.

Niemiec & Walberg (1985) provides the most inclusive meta-analysis of CBI effectiveness studies at the elementary level. This review summarizes the results of 224 studies, 162 being properly classed as CAI, and report a CAI achievement effect magnitude (ES = .46) almost identical to that discovered by Kulik, Kulik & Bangert-Drowns (1985).

A box-score assessment of the data from past reviews of CAI evaluations strongly favors CAI effectiveness. Over 90% of all comparison studies report higher achievement scores in CAI groups. Of the earlier reviews, for example, Vinsonhaler and Bass (1972) found that 8 out of 10 studies at the elementary level indicated positive outcomes. Edwards et al's (1975) review, which included 36 studies covering a variety of applications at all levels, found 22 of 36 positive for CAI, 2 negative and 12 showing roughly equivalent results. When we look at box-score results from the most recent meta-analytic reviews from the University of Michigan the same pattern appears -- all 28 studies at the elementary level favor CAI; 15 of 17 studies at the secondary level; and at the college level, 40 of the 58 studies reviewed.

Many recent effects studies have examined microcomputer applications, but few of these have been included in even the most current meta-analytic reviews. Preliminary indications are that CAI interventions using microcomputers are at least as effective as applications on time-shared systems. Ploeger's (1985) survey of such studies includes 6 microcomputer-based CAI studies which measured achievement outcomes, 4 of which report positive gains, while the other 2 report ambiguous outcomes. No study indicated that microcomputer application in CAI retarded achievement.

Kulik and Kulik's (1986) meta-analytic review of computer-based education in colleges includes 5 studies using microcomputers and reports a mean effect size of .43. Niemiec & Walberg (1985) includes 2 microcomputer studies at the elementary level with a reported mean ES of 1.26. Levin, Lietner and Meister's (1986) forthcoming study of the cost effectiveness of 8 recent CAI interventions includes 3 other evaluations of microcomputer based implementations, 2 at the elementary level and the other in a secondary school. Each of these studies report positive findings for CAI effectiveness with effect sizes ranging from .2 to .6.

Computer-Managed and Computer-Enriched Instruction

While there are relatively fewer published studies, research into the effectiveness of computer-managed instruction (CMI) and Computer-enriched instruction (CEI) date back to the earliest research into computer applications in learning. Early studies classified as CEI are, however, almost exclusively applications of computer programming exercises as an adjunct of mathematics instruction. With the growth in computer applications and capabilities, a wide range of software tools came to be used as learning aids. Research into the effectiveness of theses applications have followed. Table # provides a summary comparison of the CAI, CMI and CEI effectiveness findings reported in the most recent meta-analyses by James Kulik and his colleagues.

Achievement Outcomes in Computer-Managed Instruction. Computer applications in instruction management appear to result in moderate gains in student achievement at both high school and college levels, but has no demonstrated achievement benefits at the elementary level.

No review of CMI reports effectiveness in primary school applications. Niemiec & Walberg, for example, report 42 CMI studies at the elementary level with an average effect size of .03. Of four studies included in Kulik, Kulik & Bangert-Drowns's(1985) review only one study (Nabor, 1974) reported significant gains. Two major long-term (2+ years) studies by Coffman and Olsen (1980) and Roberts (1982) found no student achievement benefits.

At the high school and college levels, on the other hand, typical studies report effectiveness findings above 1/3rd of a standard deviation. Particularly strong findings are reported in Ray's (1977) study of CMI in beginning high school algebra (ES = .76), Roll and Passen's (1977) study of applications in college psychology courses (ES = 1.46), and Havlicek and Coulter's (1982) evaluation of CMI use in a junior college reading improvement program.

Achievement Outcomes in Computer-Enriched Instruction. Studies of the achievement benefits of computer-enriched learning environments have been carried out for most part at the secondary and college levels. While Niemiec & Walberg's (1985) comprehensive review lists 20 or 224 effectiveness studies at the elementary level as studies of "problem solving" applications, no CEI studies meet the inclusion criteria in Kulik, Kulik & Bangert-Drowns's (1985) more selective review. In any event, research to data indicates that computer enrichment applications are reliably effective only a the college level.

Kulik & Kulik's (1895) review of 28 college level CEI studies reports moderate achievement gains (Mean ES = .23). Individually, these studies have consistently modest and marginally significant achievement results with a few exceptions such as a 2 week experiment with the use of computer simulation in teaching scientific methodology which reported very large achievement gains (Green & Mink, 1973).

In aggregate, CEI achievement effects at the elementary and secondary level are slight and non-significant. Niemiec & Walberg's (1985) review of 20 primary school studies reports a mean effect size of .12 and Bangert-Drowns, Kulik & Kulik's (1985) review of 16 high school studies reports a mean ES of .07. Results from individual studies, however, suggests some promise for future CEI applications. One high school study in which programming was combined with the use of tutorial software (Jamison, Fletcher, Suppes & Atkinson, 1976) and another in which simulation was combined with tutorial (Lunetta, 1972) both resulted in strongly positive achievement findings. Results from studies of CEI applications using microcomputers with young children are also encouraging. For example, Hart's (1981) study of the use of Basic programming to convey math concepts found achievement gains among first grade students comparable to gains of third grade students using traditional curricula. Moser and Carpenter (1982) found that graphic computer aids provided unique benefits to first grade students in solving arithmetic problems. Finally, Hess and Ford (1986) report that kindergarten students using a variety of microcomputer applications in their program scored significantly higher on a achievement tests than those following traditional curricula. These authors find that benefits are most pronounced when computer use by the child is reinforced in the home.

Comparing Achievement Outcomes. CMI, and CEI applications can be contrasted with CAI with regard to both the mechanisms through which they produce student achievement gains and the magnitude of discovered effects across educational levels.

Applications generally classified as CAI are understood to affect student achievement primarily through improvement in the quality, quantity and/or clarity of student interaction with traditional curricula material. CMI, in contrast, is understood to promote learning gains indirectly, since instructional support is directed, primarily, to the teacher. Student gains can result from CMI through: (1) improved teacher-student interaction as management burdens on the teacher are reduced and management information to the teacher is improved; (2) student self-regulatory responses to improved progress and performance feedback provided by the management applications.

Computer-enrichment applications also operate indirectly to affect student examination achievement. Like CAI, CEI supports student learning. Unlike CAI, most applications classified as CEI are not designed to provide traditional course content, but rather are used -- often in improvised fashion -- to enhance the learning process. The import of achievement findings from CEI studies is, at best, ambiguous since it is often unclear whether instructional effectiveness is a primary objective in CEI implementations.

The effectiveness of different forms of computer based instructional support varies systematically with instructional level. Firstly, CMI and CEI are least effective at the elementary level in contrast to CAI which appears most effective in that age group. We explain this developmentally: younger children are less able cognitively to take advantage of diverse aspects of technology which improve learning efficiency. The less direct the supports the less likely it is that youngsters will have the cognitive skills and habits to capture their benefits. It is apparent that younger children are much less adept at the judgmental processes which would allow them to independently utilize information provided by CMI for self-pacing and individual learning efforts.

Secondly, achievement outcomes from CMI applications at the high school-level are equal to or greater than CAI outcomes. This is somewhat surprising given the indirect nature of CMI effects on learning. Available studies of CMI implementations at the 9th grade report an average gain greater that one half a standard deviation. Such positive findings from studies in the early high school years indicate that youngsters entering adolescence are fully able to benefit from the work management cues provided by CMI applications.

Thirdly, in contrast to CMI, CEI applications do not appear to result in examination achievement benefits even at the high school level. This may be due to the fact that many of the software packages employed were originally designed for use at the college level or in business or scientific applications. The additional time investment required to master these applications and persisting conceptual problems in youngsters' appreciation of software features minimizes the net benefits accruing from their use.

Implementation Contingencies and CAI Achievement Outcomes

One of the striking features on the terrain of primary CAI evaluations is the large differences in outcome findings -- ranging from mildly negative to extremely positive -- from one study to another. Most reviews support the view that these differences cannot be wholly attributed to variations in experimental design or instructional setting (cf. Kulik & Bangert-Drowns, 1984). The relatively large number of CAI studies allows meaningful inquiry into the role of implementation differences with respect to either the subject population involved or the nature of the CAI application employed. Five implementation contingencies receive attention in a broad cross-section of studies: (1) educational level of students; (2) academic aptitude of students; (3) type of CAI application; (4) course content of CAI materials; (5) quality of the technology employed. In this review of implementations contingencies the authors draw almost exclusively from the most recent meta-analytic reviews of computer-mediated instruction and their own re-analysis of CAI studies included in the most selective of these reviews. [14]

Educational Level and Achievement Effects. To date, CAI applications at lower educational levels have proven relatively more effective than those at higher levels. As indicated previously, CAI applications at the elementary level results in a performance improvement of about .47 of a standard deviation, but only .36 in High Schools and .26 at the college level. Niemiec & Walberg report a significant grade level effect in studies at the elementary level, with a group of studies in the primary grades (K-3) showing a mean ES of .81 -- about twice the magnitude of discovered effects at higher levels.

Student Ability and Achievement Effects. The preponderance of the evidence from CAI studies to date, suggests that, at both the primary and secondary school levels, low-ability students experience greater achievement gains than average or high-ability students.

Niemiec & Walberg (1985) find that implementation at the primary school level with lower-aptitude student populations result in somewhat stronger achievement results.[15] Few CAI studies are restricted to high-ability populations. Niemiec & Walberg report 3 such studies with a mean ES of .19, about half the magnitude of outcomes in average or low-ability groups. The strongest evidence of ability-based differential effects is provided by four studies of CAI implementations which report separated findings for lower-aptitude and higher-aptitude students with the subject population (c.f. Kulik, Kulik & Bangert-Drowns). In aggregated, test scores for high-aptitude students were barely affected by the CAI interventions -- with a mean ES of .06 -- , while, for the lower-aptitude sub-populations achievement scores were raised .55 standard deviations, that is, to about the 70th percentile. For each of these four studies the achievement gains relative to the control populations were greater for students pre-rated as lower-achieving than for other students.

The scholastic aptitude of the population group also appears to be an important implementation contingency at the secondary school level. In the 17 CAI included in Bangert-Drowns, Kulik & Kulik (1985), implementations with low-aptitude students produced an average ES of .45, whereas those with representative populations produced a mean ES of .20. The pattern of ability-based effect differentials in favor of low-ability groups does not, however, persist at the college level. Indeed, Kulik & Kulik's (1986) CBE review suggests that implementations with average or high-aptitude students may be relatively more effective a the college level.[16]

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[14] The authors carried out independent statistical treatment of contingency and effectiveness data from 103 CAI studies included in Kulik, Kulik & Bangert-Drowns (1985), Bangert-Drowns, Kulik & Kulik (1985), and Kulik & Kulik (1986).

[15] Though Niemiec & Walberg report this as significant, the tabled data does not appear to support statistical significance at the $p = .05$ level.

[16] Calculated ES for CBE studies in low-ability college populations is .17 in contrast to and ES of about .30 for average and high-ability groups. This finding does not, however, carry statistical significance.

Type of CAI Application. Some investigators have considered whether CAI applications which r replace conventional teaching (i.e., Tutorial style software) were more or less effective than similar applications designed to reinforce teacher presentations (i.e., Drill and Practice). Hartley's (1977) meta-analytic review of findings from applications in mathematics education reported that applications in which CAI completely replaced traditional instruction were relatively ineffective. Niemiec & Walberg's 1985 review of primary school CAI reports a mean ES of .47 for 146 studies of drill and practice applications and a mean ES of .34 for tutorial applications. While this and other similar findings have only border-line within the framework of a meta-analytic treatment of research findings, the conclusion that supplementing instruction with computers is more effective than providing a fully computer-based tutorial environment is widely asserted in summaries of the field (c.f., Okey, 1985; Fisher, 1983). This conclusion does not, however, receive support from several other meta-analytic reviews of primary studies. As early as 1983, Kulik, Bangert and Williams reported the opposite, though statistically non-significant, pattern in studies at the secondary school level. Our re-analysis of the CAI data in Bangert-Drowns, Kulik & Kulik's (1985) CBE review shows that the most effective CAI implementations in secondary schools are of tutorial style mathematics in senior grade levels (means ES = .46). Moreover, a few well-documented studies of tutorial implementations from the late 70's and early 80's have been reportedly very effective. At both the primary school level (e.g., Warner, 1979: ES = 1.31) and the secondary school level (e.g., Patcher 1979: ES = 1.44) these implementations have proved substantially more effective than either same-period drill and practice implementations or earlier experiments with the tutorial approach.

CAI Course Content. Whether one looks at drill-and-practice or tutorial applications, achievement effectiveness studies of CAI mathematics have resulted in findings which are more often statistically significant and on the average of somewhat greater magnitude that CAI effects results in other subject areas. These differences, however, are neither large nor consistent

Niemiec & Walberg (1985) distinguish studies of CAI in mathematical. problem solving from studies of effects on mathematical reasoning and find that CAI designed to develop math problem solving skills (mean ES for 35 studies = .61) is significantly more effective than CAI developed for instruction in other subject areas.

A similar pattern is found at the high school level. The 10 CAI mathematics studies reported in Bangert-Drowns, Kulik & Kulik (1985) have a mean ES of .37, while 4 CAI reading studies have a mean ES of .19. At the same time, individual studies in areas other than mathematics or reading have also proven very effective at the high school level. At the college level, on the other hand, mathematics content does not play the same prominent role as a contingency for the effectiveness of a CAI application as it does at lower levels. In the first place, at the college level, there is a much broader range of CAI applications, with CAI mathematics accounting for only one sixth of the effectiveness studies (Kulik & Kulik, 1986). Math CAI applications at the college level are also much less effective (ES = .18) than in high school or primary school. Indeed, Kulik & Kulik (1986) report's that CBE applications in less quantitative "softer" disciplines (e.g., biological sciences, social sciences, humanities) are significantly more effective than applications in more quantitative disciplines such as mathematics, physics, chemistry and engineering. Their analysis suggests that the most critical distinction is between course which deal with living or organic objects (e.g., physiology, psychology) and those with inanimate objects of study (e.g., language, mathematics, engineering). Our own analysis of the results from CAI studies included in their sample shows that achievement effects in "life systems" courses are, on average, twice as great as in "non-life systems" courses (Mean ES of .47 vs. .23).

Technology Improvements. Through the entire history of CAI research, rapid advances in computer engineering have generated continuing improvements in the speed of operations and information-storage capabilities of the technology. At the same time, it has become almost axiomatic that the flexibility of computer software development allows unbounded improvements in the design of computer applications. There has thus been, understandably, much discussion of potentially dramatic leaps in the educational effectiveness of computer applications. The evidence of the effects of technological improvements to date is sparse and inconclusive. While studies of microcomputer CAI applications have yielded effectiveness results stronger than those discovered in studies of CAI on terminal-to-mainframe configurations, these studies are too few in number and too varied in design to allow firm conclusions regarding the importance of the differences in technology. Meta-analytic reviews have typically argued that since the effects of changes in experimental design over time have so far been discounted, changes in effectiveness findings over time could probably be attributed to technological improvements. At the elementary school level, both Kulik, Kulik & Bangert-Drowns (1985) and Niemiec & Walberg (1985) report that mean effect sizes from studies carried out after the mid-70's are not notably greater that ES findings from earlier studies. Findings from research at the high school and college levels does suggest, however, a pattern improvement in effectiveness over time. In their review of 42 CBE studies Bangert-Drowns, Kulik & Kulik (1985) report a significant positive correlation between year of publication and effect size ($r = .39$, $p<.05$). The authors analysis of the 17 CAI studies in their sample of CBE studies finds a similar correlation pattern ($r = .33$, $p<.01$), with a mean ES of .28 for studies prior to 1975 compared to an ES of .46 for more recent studies. This finding is replicated in our analysis of 58 college level CAI studies referenced in Kulik & Kulik (1986): latter studies had significantly greater effects (Mean ES of .39 vs. .18); the correlation between year and effect is positive ($r = .26$, $p<.05$).

Summary

A substantial body of empirical studies finds that computer mediation has significant advantages in achieving traditional goals of instructional delivery. Effectiveness findings from comparison group studies range from mildly negative to extremely positive. Recent evaluations of CAI applications, in particular, report consistently positive and on the whole moderately high achievement gains at all educational levels. Instructional management applications appear to be effective only at the secondary school and college levels, while applications such as computer programming and illustrative simulation software, when introduced to enrich the learning process, do not appear to have any effect on examination achievement except at the college level. Research designs, however, have not been sufficiently elaborate to allow robust multivariate examination of the mechanisms which underlie these outcomes. Two factors may partly explain discovered instructional advantages: firstly, computer mediation has been found to improve student attention; secondly, some studies indicate that computer-mediation allows the same materials to be presented and learned in a shorter time-span.

The impact of CAI on achievement outcomes seems to vary with certain implementation contingencies. Most prominently, CAI applications in lower educational levels and with lower achieving students appear to be significantly more effective than in counter-part population subgroups. Also, at lower educational levels CAI drill and practice applications which *reinforce* instruction are much more effective than tutorial applications which *substitute* for human instruction. The course content in CAI implementations also seems to make a difference. A lower educational levels CAI applications in precisely defined domains such as mathematics appears most successful. In contrast, at the college level applications in more open-ended fields of study are most effective. Finally, there is a strong presumption that technology improvements result in more effective applications. This receives some support form a moderate correlation between the date of implementations and the magnitude of discovered effects.

Computers As Learning: Cognitive Effects of Computer Programming and Other Non-Tutorial Software

The most far-reaching claims regarding the potential cognitive effects of computers in education concern their use as creativity tools rather than as tutorial media. The generalized acquisition of the fundamental skills of computer use and computing, it is argued, can "alter radically both the *form of learning* and the *content of what is learned* (J.S. Brown). The peculiar set of cognitive demands of programming and the use of higher-level tools, combined with the power of these tool to create, manipulate, test and transmit information, is seen to provide unprecedented impetus for the development of procedural reasoning skills (Seil, 1981), reflective, analytic and visual thought (Paisley & Chen 1984; Steffin, 1983), and the lateral processing of knowledge (Textor, et al., 1985).

Effects of Programming on Problem Solving Skills. Most research to date has focused on the effects programming on problem-solving ability in children. There are two distinguishable (though often confounded) conceptions of the cognitive side-effects of computer programming. To highlight the differences we describe one conception as programming-disciplines-thinking and the second as programming-frees-thinking.

The idea that programming disciplines thought arose from the experience of information systems and AI programmers who found that the logical and syntactic precision required to instruct a computer to carry out complex tasks compelled the explicit statement of thought processes and the development of procedural reasoning. Sheil (1981) defines *procedural reasoning* as "the process by which one determines the effect of a set of instructions which will achieve a particular effect." Procedural reasoning is premised first on a separation of the instruction set from the processor -- since a non-human processor can not "fill the gaps." It involves the breaking down of complex problems into components, each of which can be precisely addressed, often by one of a growing body of generally applicable mathematical solution tolls, or algorithms (Paisley, 1984). Sheil argues that procedural reasoning is a "fundamentally new way of thinking" requiring types of logic not commonly acquired by individuals in the past but increasingly important if individuals are to intelligently employ complex programmed devices in the future.

The second notion, that programming frees thinking, is embodied in the philosophy propounded by Seymour Papert and his colleagues at MIT (Abelson and diSessa, 1980; Papert, Watt, diSessa and Weir, 1979) and their LOGO programming language. Papert is critical of traditional use of computer in education, including the teaching of the Basic programming language which he sees as too restrictive and limiting. Based on the Piagetian view of learning as knowledge acquisition through self-guided problem-solving experiences -- learning by doing -- the LOGO language allows a child, with minimal guidance, to instruct the computer to represent simple geometric motions and to understand incrementally more complex directions, displaying the results in graphic form. Papert believes that by teaching the computer in LOGO the child "is learning to see formal mathematics as a systematic language, a different style of articulating and elaborating what he already knows" (Papert, 1979). Papert argues that by creating computer-afforded symbolic environments the child will encounter a range of conceptual challenges (unavailable in human culture) which promote the development of cognitive skills.

To date, there are no studies which conclusively demonstrate these effects. A number of small studies indicate LOGO's ability to promote specific skills. In two studies, young children demonstrated new skills in structuring mathematical operations after experience learning and using LOGO (Perlman, 1976; Papert, Watt, diSessa, and Weir, 1979).

Gains in more general problem-solving skills are indicated in a study by Clements and Gullo (1985). After 12 weeks of bi-weekly LOGO sessions children showed gains in divergent and reflective thinking, language fluency and ability to give directions, not indicated in a control group.

Two studies have looked at the understanding of conditional statements among older children. The use of "if...then" control structures is a major part of programming. Conditional statements are also important for scientific reasoning, hypothesis formulation and testing. Seidman (1981) reports improvement in the use of conditional statement among fifth graders using LOGO. Daley and Lepper (in preparation) found that after a one-semester course in Basic, high-school students were much more likely to correctly interpret conditional statements imbedded in a larger set of natural language instructions.

A major two-year study of LOGO, however, found no significant effects on cognitive skills (Pea, Kurland, and Hawkins, 1985; Pea 1983). This study attempted to determine whether LOGO programming resulted in planning skills which could be transferable to tasks other than the writing of LOGO programs. Two classes of third grade and fifth grade students engaged in a one-year LOGO programming course were studied. To test planning skills, researchers employed a classroom chore-scheduling task which required students to "develop a plan that would allow one person to accomplish all the chores" most efficiently. Data were collected on both the efficiency of the plan -- primarily recognition and use of the spatial clustering of chores -- and the planning process -- number of types of planning decisions and the flexibility in decision choice. At the end of the first year, they found that programming students showed no advantage over non-programming students on the classroom planning task.

In the second year, new groups of students were introduced to LOGO using a more structured learning environment. The test of classroom chores planning skills was computer simulated with on-line feedback to make the task resemble programming "on its surface as well as in its deep structural feature" (Pea et. al., 1985). The results of the first year were in large measure replicated: "students who had spent a year programming did not differ on various developmental comparisons of the effectiveness of their plans and their processes of planning from same-age controls who had not learned to program." The authors suggest that transferable problem-solving skills do not arise spontaneously from unguided LOGO programming experiences, as argued by its proponents, but rather, their emergence must be supported by programming teachers "who, tacitly or explicitly, know how to foster the development of such skills through a judicious use of examples, student projects, and direct instruction."

Computer Games and Curriculum for Problem-Solving. Other ways in which computers are being used to promote problem-solving skills are through logic games, software tutorials on thinking skills, and computer simulations involving planning and analysis.

Watt (1983) notes that there is a growing effort to develop computer games which are pedagogically sound and have characteristics which promote intellectual engagement. A number of these games are being integrated into curricula designed to stimulate the development and sharpening of critical thinking skills (Sleswick, 1983; Pogrow, 1985).

One such game, Rocky's Boots, has been widely acclaimed for its combination of intrinsic appeal, intellectual challenge, and instructional intent. In playing Rocky's Boots, children build machines that model logical arguments. The elements of the game constitute a formal system in which logical discrimination must be made using Boolean and electronic-circuiting logic. In one study of the effects of Rocky's Boots, Stein and Linn (1985) found that eighth grade students gained as good an understanding of the embedded principles of logic as students who received intensive one-on-one instruction in these concepts.

An innovative attempt to employ a variety of computer learning tools in an integrated curriculum is the higher order thinking skills (HOTS) project (Pogrow, 1985). This project employs computers to promote skills used to analyze and synthesize information among fourth- to sixth-grade students in a compensatory program. The HOTS curriculum employs computer tools to (1) develop and exercise component thinking skills; (2) provide tasks which require the use of knowledge from a wide variety of subject areas. Results from the first y ear evaluations indicate that students participating in the HOTS program experience significantly greater gains in cognitive skills than comparison students using traditional curricula.

THE MOTIVATIONAL IMPACT OF COMPUTERS

Few of the major studies of the effects of computers in education considered motivational impacts. However, in the context of sweeping transformations in the economic structure and the relations between schools, homes, offices, factories (Resnikoff, 1983), increasing attention is being paid to possible effects on attitudes toward learning as well as the broad implications of exposure to the new technology on aspirations the upcoming generation of workers and their preparedness to cope with a world of computer mediated work.

Some Ethnographic Insights

A two year case study (Textor, et al, 1985) of a high school in California's Silicon Valley provides some insight into the nature of changes taking place in (1) the way in which computers are being experienced by students, and (2) possible impacts on students feelings about computers and the future.

The first phenomenon of note is the rapid and almost overwhelming rate of change. Within the space of three years the computer curriculum in this school evolved from a single course in mathematical problem solving using Basic, which catered to the most advanced and promising student, to a set of courses ranging from vocational computer training to college level Pascal. Within the period of study, the number of computers more than doubled and girls began to enroll in beginning courses in almost same numbers as boys.

Secondly, there was a large proficiency gap among students in the same level classes. On the one hand, three were the experts who did their assignments at home, served as defacto (if sometimes unwanted) teacher's aides, and who held fair disdain for the teachers level of competence. On the other hand there were the rest, generally dependent on the experts for advice and illicit solutions to the assignments, struggling on in grim determination or dropping out in frustration.

Thirdly, there were distinct cliques of the experts and their cohorts who were intensely enthusiastic about computers, spent many hours writing or copying computer programs which they would share with their network of friends and admirers. Some of these students tended to regard themselves as already a part of the adult world and had expectations of professional employment positions at least part time while continuing to pursue their education. These cliques tended to find amusement in the incompetence of other students ("the masses") and especially the generation of their parents.

There was a distinct duality in students' views of personal benefits of taking a computer course. There were those who saw a wide range of benefits ranging from improvement in cognitive abilities (or as student said: "intelligence") to providing an entree into a good job. These students were generally positive about their computer experiences regardless of practical outcomes -- as one student expressed it: ". . . hope I can get a job! But other than that, I can still have fun playing with them." Some of the poorer students also tended to be positive: "I realize I will need it . . . I feel better about myself for having this stuff." Other students, however, were less enthusiastic and somewhat cynical of the value of computer classes from an academic point of view: "some people say it makes them more confident. No it hasn't . . . it hasn't changed me any!"

The main point of agreement among almost all students was the near necessity of learning about computers in order to cope with the future. Pervasive was the impression that the computer age was upon them and there really wasn't anything to do but swim or sink.

Some Questions

Insights suggested by these field observations provide a point of departure for a closer examination of the key questions addressed in current research.

First, how do computers, used in the classroom as a tutorial device, affect student attitudes to the instructional material? Malone and Lepper (1985) suggest that several aspects of modern tutorial software, particularly the fantasy element, could make the subject matter more intrinsically interesting.

Second, how might the phenomenon of widespread diffusion of computers in social and educational environments be changing attitudes to technology among youth? Lee (1970) reported a basic dichotomy in attitudes and beliefs about computer technology in the North American population. On the one hand, there was the view of the computer as a beneficial tool for man, foreshadowing greater human productivity and leisure. On the other hand, there was the Awesome Thinking Machine perspective which simultaneously embraced notions of the amazing potency of computers and of unexplored dangers.

Third, are present levels of exposure to computers generating perceptions of efficacy and competence among youth which may substantially affect their adaptation to the social and work environments of the future? Recent research suggests that self-perceptions of one's capabilities and potential substantially mediate a wide range of achievement outcomes (Schunk, 1979; Johnson, 1980; Salomon, 1983). Indeed, self-efficacy perceptions, rooted in the interpretation of experience, is found to provide substantially more robust prediction of future behavior than actual experience or long-term goals (Bandura, 1982).

Computer-Based Instruction and Attitudes Toward Learning

Studies of computer based instructions have reported only modest effects on academic attitudes. Kulik (1983), in his meta-analysis of fifty-one empirical studies found of ten studies which considered motivational effects, eight reported that students' attitudes toward the subject matter being taught was more positive in classrooms using CBI. On the average, however, reported attitude gains were small. Of four studies which reported on students' rating of the quality of instruction, CBI classes received slightly more favorable ratings in each case.

Considering the wide range of less formal studies on the effects of microcomputers in the classroom (C.F. Fisher, 1983; Kenneth and Chapman, 1983; Paisley and Chen, 1984; Textor et al, 1985; Seymour, 1986; Zuk, 1986), one finds notably more positive reports of motivational effects in the classroom. Particularly strong findings are reported in studies of the use of computers with special education students. In addition to direct- measures of subject matter interest, indirect indicators of motivation included improved attendance and lengthened attention span.

Increases in achievement through CBI programs may reflect affective impacts of computer use. A study of eighth graders using microcomputers to access an electronic encyclopedia on a commercial videotex service found that students preferred the computer-based system to available hardcopy encyclopedia (Eastman, 1984). Students justified their preference by saying that the computer system was easier to use, despite clear evidence to the contrary. Large-scale evaluations of IBM Writing-to-Read and of the PLATO system lead some to conclude that the configuration of CAI engages students more directly than does traditional instruction:

> The social organization of learning is improved considerably when microcomputers are used-- increasing student enthusiasm and independent Student learning. (CAI:The Bottom Line)

The relationships of motivation and attitudes to achievement in CAI use are ongoing areas of study. The findings so far have been limited and inconclusive. Insofar as motivation is increased through the novelty of CAI, we can expect diminishing effects over time: "As computers become more commonplace and are used for greater durations, this stimulative effect may diminish" (Shugoll,1983).

Computer Learning Opportunities and Student Attitudes to Computers

With the rapid spread of computers in social as well as educational environments, the phenomenon of computer phobia reported in early studies (Lee, 1970) has been in general decline. Children, particularly, express generally positive attitudes toward computers and computer activities (Lawton & Gerschener, 1982) Daley and Walker (1984) report two fundamental dimensions of attitudes to computers among high school students: interest in learning about computers, and belief in the potential benefits associated with computing expertise. These two factors, however, are largely confounded in affective responses and may properly be viewed as a single construct -- enthusiasm for computers.

Kulik (1983) found that reported effects of CBI on attitudes towards computers were, on average, three times greater that effects on attitudes towards the subject matter being taught. Though only four of the studies reviewed measured such effects, in three cases the positive results were highly significant. More recent studies looking at the effects of a wide range of computer experiences -- including CAI, programming, and games -- among junior high and high school students indicate that such computer experiences are significantly related to positive attitudes (Lepper et al, in preparation; Lin & Lepper, 1985; Loyd & Gressard, 1984; Seymour, 1986).

Apart from direct experiences with computers, students are being exposed to computers through the mass media, peer models, and parental example and advice. While such *modeling*, or vicarious learning opportunities may be more likely to occur in the context of greater access to computer technology or use of computers, they can clearly occur independently of these factors. Lepper et al found that modelling factors were substantially more important that measures of direct experience in predicting enthusiasm for computers. Parental influence, in particular, was strongly associated with positive attitudes. These effects persisted when the effects of direct computer experience were taken into account.

As computers become more common-place and computer literacy courses become well recognized parts of school curricula the novelty appeal of computers will surely decline. One study in the California Bay Area (Peninsula Times Tribune, 9/2/1985) found that students who had relatively abundant exposure to computers were increasingly blase and uninterested. There is, additionally, anecdotal evidence that students who do not have access computer experiences or do not enjoy computing are becoming alienated from those students -- computers nerds -- who are intensely involved.

It is also apparent that many student who elect to engage in computer activities are already pre-disposed to enthusiasm towards the technology. One study of the effects of a introductory one-semester high school courses in Basic programming (Daley & Lepper, in preparation) found that, while students entering the program had fairly positive attitudes, enthusiasm for computers did not increase during the course of the semester. In fact, enthusiasm among some groups of students declined.

Computer Learning Opportunities and Self-Percepts of Efficacy

Students' future decisions about taking computer courses, using computers in their studies or work as well as other aspects of involvement with computers, are predicated not only on intrinsic interest and incentive factors, but also on perceptions of ability to succeed in such endeavors. Few studies have looked at self-efficacy effects but findings of robust positive associations between computer opportunity and computer confidence have been replicated among middle school students (Miura, 1985; 1986), high school students (Lepper, et.al., in preparation; Loyd & Gressand, 1984) and college students (Loyd & Gressand, 1984). Correlational data from these studies suggest computer experience more strongly predicts efficacy than enthusiasm. Daley and Lepper (in preparation) found that one semester of Basic, while having no effect on enthusiasm had significant effects on various computer efficacy dimensions. Even limited exposure to computers resulted in reduced computer anxiety, confidence in ability to use computers, self-assessments of computer competence and self-assurance of success in computer classes.

Computer self-efficacy percepts are seen to have both immediate and prospective dimensions, the former reflecting assessments of present ability, the latter self-judgment of future potential. These may also be conceptualized as affective--lack of apprehension regarding potential--and cognitive precise--knowledge of ones capabilities. Lepper and his colleagues found while self-assessments of competence was well predicted, the extent of computer experience, as might be expected, affective dimensions of efficacy were more strongly associated with modeling and social influences in the computer domain.

Computer Learning Opportunities and Youth Aspirations

Though many pages in the literature on the impact of computers have been devoted to potential impacts of computers on the structure of the workforce, unemployment and even the nature of work (see previous chapters), little attention has been paid to possible effects of the rapid diffusion of computer technology and the growth of mediated knowledge of computers on the educational and occupational aspirations of the upcoming generation of workers.

Anecdotal and inferential evidence suggests that the rapid introduction of microcomputers in the schools in the U.S. is partly responsible for an upsurge in interest in a computer science college education and information technology careers. Two of the more recent studies of international efforts considered aspirational outcomes. Miura (1984) found that first year college students who had high school computer experience were more likely than others to include computer studies in their program of study. Female students with prior experience were less motivated to take programming courses. Lepper et.al. found that school computer experience predicted somewhat higher educational aspirations even when the effects of school computer experience was statistically controlled. The school computer experience was even more strongly associated with scientific/technical and computer job expectations. As in all motivational effect domains, parental modeling and advice was found to be very important. This study also suggests that computer efficacy percepts mediate the effects of experience on aspirational outcomes. The authors find that modelling and direct experience with computers do not explain a significant portion of the observed variance in occupational expectation once the variance explained by computer self-efficacy and beliefs about computers is accounted for.

Methodological Issues and Effectiveness Findings

The single over-arching critique of impact studies to-date is that the scope of most studies is two narrow to allow the exclusion of alternative explanations or generalizability to the social system as a whole. Typical studies have experimental or quasi-experimental designs, small samples (n < 100), and few measures of possible co-determinants. Bork (1985) expresses skepticism of the value of these studies: "A vast number of uncontrollable variables are present in education, so unless one works with extremely large numbers the chances of learning anything of any consequence through comparison studies are small." More broadly stated: without larger samples which allow observation of impacts in realistic implementation contexts and research designs which allow simultaneous examination of rival explanations of discovered effects, application of effectiveness findings is severely limited.

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(1) These studies are cited in Kulik, Kulik and Bangert-Drowns (1985) and Bangert-Drowns, Kulik and Kulik (1985). As far as we can see from the reported results, they are not systematically different from the results in the U.S. Two recent German meta-analyses of a large number of micro-studies of CAI reported at the stanford/UNESCO conference in March, 1986, show no significant differences compared to traditional teaching methods, whereas another analysis shows moderately high differences (see Lehman, Jurgen and Ronald Lauterbach, "The influence of Computers in schools on Knowledge and Attitudes" Institute for Science Education, Kiel University (mimeo)).

Other scholars point to the large number and wide range of CBE studies completed under varying experimental conditions and argue that a hypothesis of "no effect" cannot be sustained in the face of statistical conclusions from several meta-analytic reviews. It is highly improbable, they suggest, that so many individual studies (while often criticizable when each is taken singly) would (erroneously) produce positive achievement findings if CBE interventions had no achievement benefits.

Ironically, it is the meta-analytic review which have themselves become the basis for the most persistent assault on past CBE research (Clark, 1983; Clark, 1985a; Leonard and Clark, 1985). Meta-analytic findings regarding two experimental contingencies -- study duration and instructor control -- have been used to argue against the validity of CBE research conclusions.

Study Duration and Novelty Effects. Research has often found that with the introduction of new communications technology usage tends to peak initially and then trail off towards a baseline level as the technology loses its novelty or becomes commonplace within the social group. Clark (1983, 1985a) argues that similar "novelty effects" account for discovered benefits of computer-mediated instruction. Using data from early meta-analyses of CBE studies he notes that at the elementary and secondary school levels " the advantages for computer delivered instruction diminish to significant levels with time" (Clark, 1985a). Recent meta-analytic reviews do not, however, sustain support for significant novelty effects. Effect size findings for long-duration studies (more than 1 semester), taken alone, are moderately positive and statistically significant. Additionally, whereas the average outcome magnitude for short-term studies is greater that for long-term studies,[17] the difference remains statistically insignificant when all studies are examine together as well as in separate analyses of studies at each educational level.

Finally, it is worth noting that smaller effect-size findings from long-term studies could be due to the inability of long-term research programs to accurately capture the outcomes of these interventions. Kulik, Kulik & Bangert-Drowns (1985b) observe that "long-term studies provide better control for novelty effects, but the short-term studies may provide better control over other extraneous factors. In short-term studies, for example, criterion tests may measure more exactly the material taught by the competing methods" (1 (4): p. 384).

Instructor Control and Effect Migration. When the instructor who orchestrates the computer-mediated learning experiences also provides instruction in the comparison non-computer setting, discovered effectiveness gains are typically smaller and more often non-significant. Table # compares effect size findings for same-instructor and different-instructor CBE studies on the basis of data from the most recent meta-analytic reviews. The largest discrepancies (approximately .1 standard deviations) register ant the secondary and college levels. Clark (1985a) suggests that CBE effectiveness findings are in large measure due to uncontrolled *method differences* between computer and conventionally delivered courses. Weaker results from same-instructor studies is interpreted to result from improved standardization of *instructional method* across computer and traditional settings.

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[17] Note: Kulik, Kulik & Bangert-Drowns (1985) reports a mean ES of .26 for long-term CBE studies versus .34 for short-term studies.

Clearly, controlling for instructor effect does not reverse effectiveness findings from CBE studies. Kulik, Kulik & Bangert-Drowns (1985b) note that in same instructor studies the average effect was to raise achievement scores by .24 standard deviations as compared to .38 for other studies. Each result achieves statistical significance. Reportedly, the difference is statistically nonsignificant (at $p < .05$). At the same time, the substantial size of the difference and the suggestion by the Kuliks and Bangert-Downs that the difference is due to a "diffusion of the innovative treatment to the control condition" argue for the validity of Clark's contention that computer-independent aspects of instructional method are the effective causes of CBE gains. Certainly, the computer *per se* is not an aspect of the CBE treatment which diffuses. Computer-independent elements of instruction can reasonably be expected to migrate from one setting to another in single-instructor experiments.

Research on computer mediated learning has typically paid little attention to an explication and measurement of the elements of instruction and learning involved in computer interventions. Thus despite the growing body of empirical studies in the field, there remains considerable ambiguity as to whether discovered outcomes result from processes that are truly computer-dependent.

DISCUSSION: THE EFFECTS DEBATE

The eventual dominance of computer-based material is not dependent on research findings regarding its power as an instructional device, but is rather a function of powerful economic and consumer market factors in the industrialized countries. The urgency of resolving the effects research question is thus somewhat debatable. Also widely debated is the significance and relevance of research findings to date. We conclude the present chapter with our contribution to the debate in these areas: (1) the relation between hypothetical and real effects; (2) the size of discovered effect; (3) the role of modeling influences in achieving desired outcome; and (4) the novelty factor and long term effects.

Hypothetical Versus Real Effects

Most of the effects findings we have reviewed are not descriptive of what is actually occurring in education but rather indicates the type and magnitude of effects which could occur under given conditions with specific technology implementation. In the case of achievement effects of CAI, the consistency of findings across a range of settings and research designs suggest that discovered effects will persist with expanded implementation.

It is often stated that the "real" effects of computers in education are the longer-term social consequences. Such consequences, however, are fundamentally dependent on postulated direct cognitive and motivational impacts. If direct impacts are not determined, it is highly speculative to propose societal consequences.

Effect Size: Big Expectations, Small Effects

Fabulous claims regarding the power of computers to transform education has led some to view the modest findings of research with measured skepticism (e.g., Grabe, 1985). In the case of CAI research, however, the magnitude of reported effects -- though modest in comparison with content intervention such as reinforcement and personal interventions such as peer tutoring -- compares favorably with effects findings in studies of other technology interventions such as programmed instruction (Walberg, 1984).

A social learning analysis suggests that only slight effects, if any, can be expected from most of the implementations studied to date. Firstly, the proportion of student time spent with the computer in typical interventions is minuscule in comparison with total amount of time that a student is engaged in cognitive activity. Typical studies evaluate the effects of one hour per week or about 30 hours per year of computer use. This is little more than the average student's weekly exposure to television. A school program in which all instruction was computer-based or the substitution of LOGO for television viewing would form empirical bases for studying hypothesized effects. Since, from a social learning point of view, individuals learn from the full spectrum of interaction with their environments, it is clear that computer-mediated experiences should make minimal direct contributions to learning and cognitive development as long as the "microworld" afforded by the computer forms only a small fraction of the individual's symbolic environment.

Secondly, (though content of computer intervention provides a basis for only small effects) the curriculum in computer based instruction experiments is generally the same as traditional programs of study. What is learned is what is taught. Despite pervasive claims (and some evidence) that computer mediation shortens learning time, experimental interventions fail to employ appropriately expanded curricula and performance criteria. If computer-based instruction does not introduce different knowledge or more, there is slight reason to expect profound differences in what is learned. To expect major differences in knowledge acquisition purely on the basis of the computer's advantage as a delivery medium is to underestimate the flexibility of human cognitive functioning. With appropriate performance criteria and incentives, humans will exercise their capacity to appropriate knowledge from media whose surface features pose diverse challenges to attention and comprehension.

Thirdly, the philosophy of *learning by doing* being implemented in experimental cases of programming instruction for children should anticipate a very slow process of learning. What Bandura (1977) says about learning in general applies equally to attempts to promote problem-solving skills through unguided computer programming experiences: "Learning would be exceedingly laborious, not to mention hazardous, if people had to rely solely on the effects of their own actions to inform them what to do" (p.22). Papert's LOGO philosophy, while placing valuable emphasis on the need for active mental engagement in effective learning, promotes a fundamental misconception about how children learn. Intellectual development does not proceed as LOGO practice might suggest, from a child's interaction with environments which he/she creates, but from interactions with the environment in which he/she finds himself/herself, which are created by other humans. It should come as no surprise that a number of studies of the effects of computers on problem-solving ability suggests that new reasoning skills and solution strategies are most likely to emerge from guided experiences explicitly designed to foster them (e.g., Stein and Lin, 1985). By stressing .us unguided learning of LOGO, its proponents, in effect, ask each child to "reinvent the wheel" before he/she can energetically and confidently employ the powerful algorithmic tools of modern software to explore expanding domains of computer-mediated creativity and learning.

Modeling Influences and Computer Literacy

One of the major arguments for computers in schooling is the need in an increasingly computerized society to allow students experiences which promote positive and efficacious attitudes toward the technology. Some research suggests, however, that such motivational outcomes can be produced by modeling influences available from parents and peers. Neither is there reason to doubt that information about computers through other media such as film will fail to achieve positive motivation goals. Indeed, many learners will fail to achieve in their early efforts the kind of satisfying experiences with computers to which they can be introduced vicariously.

The Novelty Factor and Motivation

There is some indication that achievement gains from computer-based learning are in part due to the motivational consequences of the use of celebrated and novel technology. To the extent that this is the case, discovered effects of CBI may diminish over time. There is no evidence to date that this is happening. Indeed, larger effects are reported in more recent studies of CBI, possibly due to improvements in instructional software.

Motivation does, however, constitute a major problem, primarily because the opportunities for creative activity (and their postulated outcomes in intellectual growth) require persistent effort on the part of the learner. Brown (1985) proposes collaborative learning in "electronic communities" of shared interest as a means of providing the communal support mechanisms required to sustain motivation.

Experiments such as IBM's Writing-to-Read support the argument that computers can motivate learning by allowing children early exercise of higher-level skill in their natural context rather than focusing on mastery of the isolated subskills of the education process. Insight from social learning research suggests that computers can provide invaluable motivational aids to learning if they peculiarly allow students to enjoy self-satisfying accomplishments.

CONCLUSION

Research on the effects of computers in education is in its early stages. Many small studies have indicated modest academic achievement gains from computer-based instruction. Most of these studies have used very general achievement measures employed to assess traditional curricula. There is obviously a need for studies that delineate more precisely the features of computer applications which determine instructional effectiveness, as well as aspects of cognitive effect which are not typically assessed in traditional examinations. Studies of the effects of programming and other "thinking-skills" applications have not yet borne fruit. This will undoubtedly be a major focus of study in the future. While comparatively little research has examined the motivational consequences of computer use, exciting preliminary findings suggest that this will be an increasingly important area of investigation as computer technology becomes an integral part of daily life in many societies.

Chapter V

COSTS AND COST-EFFECTIVENESS OF COMPUTERS IN EDUCATION

We have shown that computers can raise pupils' academic performance in school. Microcomputers have also become much cheaper since the late 1970s, declining in cost per unit of performance about 50 percent between 1978 and 1984. But computer hardware is still relatively expensive for most countries, and, as we shall demonstrate, hardware represents only a small proportion of total computer costs to schools. Thus, the relationship between the "effectiveness" of raising academic performance and its costs (as compared to alternative academic interventions in schools) becomes particularly relevant for school districts or nations deciding whether or not to invest in computer education.

Analysis for the a highly "computerized" country -- the United States -- suggests that computer-assisted instruction in primary schools can be cost-effective when compared with other educational interventions, although cost-effectiveness depends very much on how intensively installed systems are utilized. Therefore, there is a distinct possibility that *under certain circumstances* computer-assisted instruction could be an important tool for improving pupil performance in school.

Let us note an important caveat to this analysis: Increased pupil test scores are only one measure of the effectiveness of microcomputers in school. As we have argued, many of the decisions regarding computers are made on the basis of developing computer literacy rather than increased pupil performance in academic subjects. If preparation for the workplace through computer literacy is the major reason for investing in computer education, a different analysis has to be used than we outline here. In that case, we still have to measure the costs per pupil of computer education, but need to use as a measure of effectiveness, the future labor performance of school graduates (for example, are those with computer education more likely to earn higher incomes or obtain computer-related jobs than those without?). We would also want to know how a computer literacy intervention compares to other educational interventions in increasing labor force performance. In undertaking cost-effectiveness analysis of computers in education, then, it is crucial to measure effectiveness using outcomes that relate directly to the policy intent of the investment.[18] If there exist multiple intents (and therefore multiple outcomes), costs have to be assigned to the various uses and overlaps between the outcomes also have to be accounted for.

COST-EFFECTIVENESS AND EDUCATION

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[18] This would properly be defined as a "cost-benefit" analysis rather than cost-effectiveness analysis because incomes rather than test-scores are used as a measure of outcomes (see Levin, 1983), but can be viewed as part of the general range of cost-effectiveness studies.

The notion of cost-effectiveness in economics owes much to industrial. commercial and military research. The task of applying the rigors of cost-effectiveness assessments to education has only recently begun (Levin. 1983). although much attention has been paid to specific costs in education throughout the twentieth century. If it is reasonable to consider education as an industry, then it should be possible to examine the impact of technology on cost-effectiveness in much the same way as it is to examine the impact of robotics and microprocessors in the automotive industry or the effect of new fertilizers upon crop yields in the agricultural industry. We are conscious of the fact that in this mode of analysis we risk "dehumanizing" education into an engineering "problem" in which the technological components are cognizable and can be solved with the correct application of more efficient technology. (See Freire, 1970, for a full discussion of this tendency among academic researchers, especially the introduction and the forward by J. Kozol.) We recognize as well that a unique approach to analyzing costs and effects will be necessary as the philosophical underpinnings of education and the creative potential of education are challenged and thereby change over time.

It would be more convenient, in traditional economic terms, if education could be regarded as an industry with the same characteristics and categorical imperatives as the typical subjects of economic analysis. Even neoclassical economists of education. however. see that education is a unique activity requiring a unique perspective. For example, Blaug (1970) says that education, like industry, absorbs materials and resources. but in most countries these are collectively provided and financed through government agencies. Inputs such as teachers and buildings are bought in the marketplace, yet the output of students is not marketed by the schools themselves. Education's production cycle is unusually long, yet it consumes more of its own output (educated students) than most industries do when it employs them as teachers. Education makes no profits, yet it produces pay-offs over a long period, during which they depreciate only slowly, although that depreciation rate is increasing as the life of knowledge decreases in many fields. Education both diffuses knowledge and adds to knowledge, and it sometimes fosters and sometimes impedes social and occupational mobility. It is thus difficult to correctly measure, much less compare, the effect of a technological aid to education such as the microcomputer.

Schultz (1963) points out that "schools are not organized and administered for profit. The assets of educational institutions are not listed on any stock exchange. Students, or the families supporting them, do not as a rule pay all of the costs that are incurred in schooling." Vaizey (1972) declares that industry, in general, has distinguishable inputs, processes and outputs. Its inputs and outputs are not only more or less tangible but are also bought and sold on the market. Its processes change partly as a result of changes in relative prices on the market. Technical relationships between inputs and outputs can be clearly stated. Obviously, none of these relationships can be assumed in analysis of educational cost-effectiveness.

COSTS OF COMPUTER-ASSISTED INSTRUCTION

"Obtaining costs in order to determine the set of economically feasible alternatives is the first step in educational planning" (Jamison, Klees and Wells, 1978, p. 19). Since financial constraints severely limit the potential gains from any planned introduction of microcomputers into developing countries' educational programs. the costs of computer-assisted instruction are crucial in understanding the resource demands and the potential relative pay-off to introducing microcomputers in schools.

Microcomputers 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" (Levin, 1985, p. 28). Hardware costs represent only a small part of the total costs of the educational applications of the computer (see Appendix Table 5-1).

To estimate the costs of computer-assisted instruction (CAI), Levin proposes an "ingredients approach," which ascertains what ingredients are needed to deliver a certain kind and level of educational services, the costs of those ingredients, and who pays for them.

The ingredients themselves can generally be divided among personnel, facilities. equipment, supplies and all other. Personnel includes teachers, specialists, administrators, and equipment maintenance personnel (often in unusually short supply in developing countries). Facilities refer to the physical space required for the microcomputers and any additional elements needed to support the computers in that space, such as air conditioning, security devices, and -- particularly in developing countries -- the necessary electrical power to run the equipment. Equipment refers to the hardware and all the peripherals. Materials and supplies include the software, paper foı printing, and instruction manuals. The other category should include the costs of energy (heating. lighting, and power), maintenance, and training of personnel (none of the cost studies for developing countries we reviewed include the cost of training cadres to run and maintain the microcomputers and peripheral equipment).

A great deal of care has to go into accounting for all the ingredients. For example, enough software has to be purchased to use by all students using the computers. Many countries must install or rent cables for closely-networked computer systems or instal an electrical system that is compatible with the technology as developed or purchased by the particular school system.

Attaching costs to the ingredients is usually done through market pricing, on the principle that even though an ingredient appears to be "free," there is still an opportunity cost attached to it -- there are alternative uses for each ingredient.[19] For

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[19] Since teacher (or supervisor) costs associated with an educational intervention are one of the most significant expenses on which we have to place a value, the price we use for teacher opportunity cost is particularly important in overall intervention costs. From the point of view of the school administrator on a fixed budget but with some scope for choice in deployment of those funds, the teachers cost what they have to be paid, as any additional expenditure on teachers means a corresponding reduction in funds available for other uses (equipment, books, heating, and so on). The cost of teachers is therefore the opportunity cost of other inputs that have to be forgone, and may be represented by the amount of money the administrator has to pay in wages. This amount will be equal to zero if the salaries are paid directly by the department of education. In the latter case, the cost of teachers is zero to the school administrator but not to the department of education. From the point of view of the society as a whole, assumed only for purposes of this analysis to

"capital costs" it is worth including both the purchase price of equipment and an annual amortization of such equipment.

It is also worthwhile distinguishing between capital (investment) expenditure and operating expenditure (labor and other repeating costs). This distinction allows comparison of the cost of the primary stage (what Levin, 1985, calls "up-front" costs) and the current operational costs of an established system.

Finally, costs should be classified by contributor. This classification distinguishes between costs which are to be met by the organization responsible for capital investment, costs to be met by users, and costs falling to the community (for this last category, see UNESCO, 1977). The distinction can be particularly useful in instances where the proportion to be met by the users and community is substantial. Its importance is heightened by the fact that the evaluations made in the studies we have reviewed often tend to underestimate or overlook these categories completely. For example, take a project that relies on use of an existing telephone line. The direct cost of the operation -- the only one generally reckoned -- does not include the use of this line because it appears to be provided free of charge, except for normal user charges. Nevertheless, the cost of setting up switching stations, cables, and transmitters were incurred at the outset with a view to the full-time use of the line. This investment should therefore be charged proportionally to the educational system. Failure to reckon this and a host of more complex indirect costs is "tantamount to self-delusion concerning the real cost of such an operation, since it amounts to believing that there will always be ready-installed" equipment "with available hours that can be 'appropriated' free of expense" (Orivel, 1980). Similarly, if

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be represented by the government, the situation is different. Teacher pay will be a precise measure of the true costs of teachers to society only if we can assume a smoothly functioning, purely competitive economy in which all prices, including all wages and salaries, are determined by the equilibrium of demand and supply. In such a purely competitive world the pay received by teachers would be an accurate indicator of the value to society of their time if employed in other ways. In other words, expenditures on teachers would then be a good "indirect" indicator of true costs.

It is as yet unclear how good an approximation to real opportunity costs to either individuals, officials or the society at large the expenditures on teachers' wages are. The most obvious distortions will arise where there are either large numbers of qualified persons seeking employment as teachers but unable to find such employment at existing rates of teacher pay or large numbers of unfilled vacancies in the teacher force.

In practice, teacher pay is the simplest indicator of the cost of teachers' time, but it measures the value of that time directly only in the very limited perspective of the school administrator on a fixed budget with narrowly circumscribed options in the allocations of funds. Teacher pay is at best only an "indirect" indicator of real costs from the perspective of individual teachers, society at large, or even the governmental authorities that define the size of school budgets and the scope for choice on the part of school administrators. We may therefore conclude that if in most cases teacher pay is used as a measure of teacher costs, it is because, practically, it is the simplest and most readily available indicator.

part of the cost is met by the student (the purchase of a video display terminal. for example), failure to include it amounts to shifting the cost of education system from the public sector to the individual.

Planners of educational interventions often face a number of problems in developing such cost estimates. There are, for example, discrepancies between projected (provisional) costs and actual costs as the project is carried out (execution accounts); discrepancies between nominal costs or expenses and the real costs of using resources in one way rather than another; and problems in the treatment of costs that are incurred in large lumps for production of resources to be used over more extended periods of time. Related though somewhat different problems arise when an initial investment entails a commitment to a sequence of future expenditures (resource inputs).

When decisions are being made about a new project, only estimates of future costs are possible. Such estimates are summed up in provisional budgets. However, an analysis of what projects in fact have cost must draw on evidence looking back from a later date on what actually happened. Analyses of actual experiences then provide a foundation for more realistic provisional budgets for similar or related new projects. These experiences may serve also as warnings to signal the kinds of error and likely sources of serious waste that might be avoided in future undertakings.

Unfortunately, documents showing the evolution of costs appear only after considerable time has elapsed, and often they are difficult to obtain. This is especially true at this point in history when microcomputer interventions in developed and developing countries' educational programs are rather recent. This problem is simple enough conceptually, but it can be serious in practical terms. There are many examples of this involving other areas of educational innovation, such as television-assisted instruction (see Unesco, 1980).

EMPIRICAL STUDIES OF CAI COSTS

There are few empirical studies available of CAI costs and these are limited to highly industrialized countries, particularly the United States. There are, however, a number of articles that are useful in the task of listing and summarizing the latest hardware and software and relative price ranges applicable to education (see, for example, Pressman and Bloom, 1984). They break down costs into the categories of hardware, user training, maintenance, installation and software, and give as an example the adjusted yearly costs of CAI, with relevant suggestions for cost-cutting.[20]

The best and most complete costing of CAI has been undertaken in the United States, as part of a series of cost-effectiveness analyses of computer and other

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[20] Also see Bank and Williams (1983); Mason, et. al. (1982); Hoover and Gould (1982). They discuss administrator time, consultants, machine maintenance, backup systems, appropriate furniture, insurance and staff training, although none in great depth. A useful report containing recommendations on hardware, software, and training of instructors may be found in Topp (1985). Finally, a beginner's guide to the nuts and bolts of costs and choice of systems is Williams (1984).

interventions (Levin, Glass, and Meister, 1984; Levin, 1985; Levin, Leitner, and Meister, 1986). The ingredients for their approach are based upon a previous evaluation of a drill-and-practice application in the Los Angeles School District (Levin and Woo, 1981). However, in this most recent cost study of CAI in Los Angeles, the costs of computer hardware, software and maintenance were updated to March 1984 to take account of a sharp decline in the price of hardware between 1980 and 1984. This analysis is the most methodologically sound study to date, and is worth examining in further detail.

In the CAI configurations analyzed (described in detail in Appendix Tables 5-1, 5-1A, and 5-1B) the CAI coordinator is responsible the overall functioning of CAI including scheduling and coordination of instruction, reporting to teachers on student progress, and monitoring of equipment functioning and maintenance. This coordinator role is served 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.

Although not discussed by Levin, Glass, and Meister, one significant concern for developing countries' educational systems on the local, national and regional level is implicitly raised by this scenario. Who is going to train the teachers and aides in the use, monitoring, maintenance and the repair of this new technology? What organizations will set the timetables for the introduction of what kinds of technological innovations, and who will guarantee the needed concurrent development of infrastructure and support systems? Here is where cost-effectiveness data would be most critical, and here is where the literature is almost totally lacking.

Facilities include a classroom for the CAI laboratory, renovation for built-in counters, chairs and other furnishings, air conditioning, and security devices. These resources are quite scarce for many developing nations, and would be nearly impossible to obtain on a mass level given current and past educational budgets in developing nations. Equipment and materials include the minicomputer, 32 terminals, a printer, curriculum rental, and supplies. All the hardware and software costs are based on prices quoted by the provider, Computer Curriculum Corporation, in March 1984. Finally, the costs include training costs, maintenance and insurance. Details on most of these ingredients and the costing procedures are found in Levin, Glass, and Meister (1984), and are summarized in Appendix Table 5-1, below.

The total cost per school for a fully-equipped computer laboratory, personnel, and other requirements (based on 736 sessions per day for one year) are about $87,000 a year for an annual cost per student per 10 minute daily session, of about $119 U.S. at 1980 prices. In 1978 the cost of a similar system was estimated at $136 U.S. per student (Levin and Woo, 1981), so a combination of 1984 hardware and software costs and 1980 costs for other ingredients reduced the overall cost per student by only about 12 per cent, despite a large drop in the cost of hardware. Some analysts assume that declines in hardware costs will substantially reduce the costs of CAI, but hardware costs represent only about 25 percent of the total estimated costs of this CAI intervention. That is, three- quarters of the cost for delivering the CAI services is not associated with the hardware, so even drastic declines in hardware costs would not reduce the overall cost per student by very much. What is important to keep in mind is that the CAI intervention requires considerably more than hardware to provide CAI services.

Levin, Glass, and Meister note that since 1978, many schools have acquired microcomputers. They ascertained the hardware cost of a microcomputer approach to compare with the minicomputer approach used in their evaluation. "This comparison is especially relevant because it has been asserted that a shift in technology over time from a centralized system based on a minicomputer to a decentralized one based on microcomputers has resulted in a cost reduction of two-thirds (Pogrow, 1983). Although the software used in the CAI intervention is not presently available for microcomputers, we think that it would still be useful to compare the costs of hardware required to deliver similar instruction with a networked system of microcomputers." (Levin, Glass, and Meister, 1984).

Their review of recent surveys suggests that a common configuration would be the use of Apple IIe microcomputers linked in a Corvus network known as Omninet (Piele, 1984). Another such system, more versatile because it can directly link Apples. IBMs, ATTs. and (soon) any other microcomputers together in a networking function is being test-marketed by Centram West, a Berkeley-based company that developed the system for Apple, Inc. Such a system must provide the opportunity for both instruction and the storage and reporting of pupil programs. This configuration requires 32 Apple IIe computers for the students and one through which the teacher monitors the local network. In addition to the storage capacity of each of the microcomputers, memory is provided through an 18.4 megabyte hard disk device for systems programs and student records. Unlike the minicomputer approach with its central storage of curriculum, each student is provided with a diskette containing the curriculum and a record of progress that is inserted in the disk drive to "load" the information into the microcomputer at the outset of each student session. Periodically the coordinator will transfer these records to the hard disk storage device to prepare student reports for classroom teachers. Appendices B and C show the hardware and maintenance costs of the comparable minicomputer and microcomputer network approaches, respectively.

Lifetime of the equipment was assumed to be identical in both cases, although the present state of the art indicates that heavy use of the microcomputers and local network might limit its life to a shorter period than the six years over which Levin, Glass, and Meister annualized the costs. Of special concern is the durability of the terminals. The terminals used in the minicomputer configuration are commonly used in offices for data input and processing and are designed to stand up to constant use in the workplace. The Apple IIe was not designed to be used for such a purpose, and particular problems with the keyboard and disk drive seem to emerge under heavy use.

The results of Levin, Glass, and Meister's research show that the costs of the two systems were roughly comparable, with a slight edge given to the minicomputer approach. This small cost advantage of the minicomputer hardware configuration over the microcomputers and local network would probably be substantially greater if one were to account for all of the ingredients and their costs, and especially difference in personnel needs. Experience with both approaches suggests that the microcomputer network, at present, is complex and unpredictable enough to require substantially greater surveillance and knowledge of the system by the coordinator than does the minicomputer approach. Such a person would need greater training and experience with computers than the coordinator for the minicomputer version, so personnel costs would be higher as well for the microcomputer-based systems. As Levin, Glass, and Meister point out, however, given the rapid development in technology, this gap in fulfilling personnel needs may narrow in the future as local instructional networks become simpler and more reliable, "but it is a consideration that must be incorporated into cost comparisons at the present time."

In addition, the fact that elementary school students must "load" their own diskettes for each session suggests a heavier use of teaching aides than the minicomputer approach where pupils need only "sign-in" by typing in their names to initiate a session. Finally, the fact that the Apple IIe is relatively slow to load a program means that a ten minute instructional session may actually take 12 minutes or longer, lowering the capacity for each terminal to handle the 23 users/day under the minicomputer approach. Although all of these problems might be overcome with a more sophisticated network (as Centram's may prove to be) and the addition of greater storage capabilities (as are presently being introduced into the Amiga microcomputer), such changes would add substantially to the short-term cost of a microcomputer network.

Levin, Leitner, and Meister (1986) reviewed 88 other computer education evaluations in the U.S., of which three-fourths had been implemented in elementary, middle, or secondary schools, and about on-fifth in colleges and universities. The remainder were taken from non-school sites such as workplaces and the military. From these they selected eight of the evaluations which met criteria allowing comparability of costs and effectiveness.

The costs per pupil of these CAI interventions are shown in Appendix Table 5-4. They suggest a wide variation in actual and full-utilization cost per student, on the average much higher than the Los Angeles cost of $119. Full-utilization cost is also much lower than actual cost, suggesting that the utilization rate of available equipment and software is crucial in CAI cost. Consistent with the Los Angeles data, however, is that personnel cost constitute about one-half of total cost, and hardware, only about one-tenth. Thus, even drastic reductions in the cost of hardware in a developed country such as the U.S. do little to reduce the cost of CAI.

Yet, this may be somewhat less true in countries where teacher costs are much lower relative to hardware costs (whose level is set in the industrialized countries). For example, if the cost per primary school student in Mexico is less than $200 per year, we would guess that the cost of a teacher-supervisor for CAI should be about one-fourth the cost in the U.S. and facilities costs would also be much lower. If all other costs remained the same, hardware costs would climb to almost 20 percent of total costs. Software would represent another 20 percent of total costs, with the rest in maintenance, personnel, and facilities. Thus, even with much lower teacher costs, hardware is still not the major cost item in a CAI delivery system.

EMPIRICAL COST-EFFECTIVENESS STUDIES OF CAI

Computer-assisted instruction has been studied for cost-effectiveness in numerous experiments in North America and the United Kingdom and in an increasing number of studies in other developed countries (especially South Africa and Australia), but the few studies undertaken in developing countries are extremely limited in their presentation of "data." Thus, the literature has yet to address adequately the questions of cost-effectiveness of computers in developing countries. There is a plethora of uncritical, speculative writing on the potential of computers to reduce costs and remove financial barriers to education, but it is not backed up by any empirical analysis (see, for example, Khoo Goh Kow, 1982, and Becker, 1982).

Other articles lay out the "broad scope" of the problem of introducing computers in education but , again, do not give us hard analysis of what computer education costs or the effects that it has on learning or employment (see, for example, Levinson (1985), Edwards (1985), Weinberg (1984), McKay (1984), and Reeve (1984)). These purport to map out the problems involved in assessing cost-effectiveness, but none successfully accomplishes that task.

The study by Levin, Glass, and Meister (1984) already discussed above meets the criteria for a successful cost-effectiveness study. Costs are measured according to a predetermined set of criteria and effects can be identified with the intervention itself. 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 by 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 received CAI and those who did not.

The drill and practice approach of the Computer Curriculum Corporation is the most widely-used CAI intervention of its type. Effect sizes in Levin, Glass, and Meister (1984) are based upon reanalysis of the results of the four-year experiment carried out by the Educational Testing Service in the Los Angeles Unified School District from 1976-1980. Effect sizes are associated with each ten minute daily session in a subject. The mean effect size in each area is based upon an equal weighting of the three mathematics sub-tests and two reading sub-tests. The largest effect size in mathematics is for computation, with a smaller effect for application and virtually no effect for concepts. The two sub-scores (vocabulary and comprehension) for the reading effect are in much closer agreement.

The Levin, Glass, and Meister study compares these effects of the CAI intervention in U.S. elementary schools with the effects of other interventions -- cross-age tutoring, an increase in instructional time, and reducing class size -- and the costs of each of the interventions. The results are shown in Appendix Tables 5-2 to 5-4. Effect sizes (Table 5-2) were estimated in terms of achievement gains in standard deviation units. However, a standard at the elementary level is approximately equal to a year of achievement, where an academic year is equal to ten months. Achievement results have therefore been converted into months of student gain per year of instruction at the elementary level.

"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 in mathematics than reading. Finally, the effectiveness of an additional half hour of instruction in each subject showed very small gains.

"Appendix Table 5-3 shows the costs per student of each intervention. The 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.

"When costs for each intervention in Table 5-3 are combined with the effectiveness results from Table 5-2, cost-effectiveness ratios are obtained. With these it is possible to ascertain the expected gains in student achievement associated with a given cost. Appendix Table 5-4 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 minicomputers rather than microcomputers, analysis of microcomputers for this specific CAI intervention suggests that they would be more costly and would be associated with lower rather than higher cost-effectiveness ratios." [The preceding analysis is taken directly from Levin, 1985, pp. 39-41, with permission of the author].

Levin, Leitner, and Meister (1986) also compared the costs of a number of CAI interventions (Appendix Table 5-5) and the cost-effectiveness of CAI interventions at five different elementary school sites in the United States using the same drill-and-practice package (from the Computer Curriculum Corporation). All these programs were directed primarily at disadvantaged children. Furthermore, the CCC package is relatively teacher-proof, so that effectiveness would be expected to be similar in each site. This was not true, as Appendix Table 5-6 shows. There is a large variation between sites, especially in math scores, largely related to the cost per student -- that is, to the way CAI was applied in each set of schools. Once costs are taken into account, the variation is considerably reduced, but not entirely, and we also note that the utilization of the system plays an important role in its cost-effectiveness.

These comparisons suggest that CAI, at least in a computer-rich country like the U.S., not only can be used to increase pupils' academic performance, but can do so in a way that compares favorably in cost-effectiveness terms with other interventions.

Nevertheless, CAI's cost-effectiveness is highly dependent on the degree to which its capacity is utilized. Once a system is installed, it may be much more cost-effective to use it to capacity than to move to other interventions.

SUMMARY

Although few studies exist anywhere of the costs and cost-effectiveness of computer-assisted instruction, the empirical research done in the United States suggest how costs of CAI should be estimated and what the possible results of cost-effectiveness studies may be in other countries. Aside from the many problems of measuring the effects of such interventions (the use of acceptable experimental methods, for example), cost studies in other countries need to pay considerable attention to detail in order to make them comparable to other interventions and to other studies of CAI. "The time investment required to identify the details of the interventions and resource requirements for the eight interventions that were assessed in this study exceeded by a factor of 20-30 the time required to estimate effect sizes. Future cost-effectiveness analysis would benefit greatly from a detailed and comprehensive description of the CAI interventions and the types and amounts of personnel and other resources that were used" (Levin. Leitner, and Meister, 1986. p. 38).

Such studies are also subject to significant change should the educational software available change. Both cost and effectiveness results are based on existing software. If there are major breakthroughs in the way computers can teach children to learn mathematics and reading, all these results could change drastically.

APPENDIX TO Chapter V

TABLE 5-1. 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 (includesCPU at $1,500, terminals at $3,200, and printer at $100)[a]
6,400	Curriculum rental per year
3,000	Supplies

TABLE 5-1 (cont.) APPENDIX A: COMPUTER ASSISTED INSTRUCTION INGREDIENTS AND COSTS *MINICOMPUTER* SYSTEM

Annual Cost	Ingredient
	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.

Source: Levin, Glass and Meister (1984)

Table 5-1A COMPUTER ASSISTED INSTRUCTION *MICROCOMPUTER SYSTEM*
HARDWARE AND MAINTENANCE ONLY

Number of Students: 736 (assumes 23 sessions per student microcomputer per day for 32 microcomputers)

Annual Cost	Ingredient
	EQUIPMENT (Hardware only)
$ 3,813[a]	Corvus OMNINET local area network with 18.4 Mb storage,interface with video cassette recorder, disk server, print server (for up to 3 printers), 33 transporters, tap cables, network cables, tap boxes and installation guides at $16,605 (includes 30% discount off list price), annualized at 10% over 6 years[a]
7,539[a]	33 Apple-IIe (32 student and 1 teacher) microcomputers with 64K memory, disk drive, green monitor and 80-column card at $32,835 (discounted), annualized at 10% interest over 6 years[a]
184[a]	1 Epson FX-100 dot matrix (220 cps) printer with cable at $800 (discounted), annualized at 10% interest over 6 years[a]
1,061[a]	Protection equipment (includes 33 microcomputer fans, desktop anti-static mats, 9 high quality, 4-outlet surge suppressors with on/off switch,cord, and 1 stand-by power unit for the hard disk system) at $4,620, annualized at 10% interest over 6 years[a]
	OTHER (Maintenance only)
9,432	Maintenance (includes network at $3,311 and microcomputers at $5,621,computed at 18%);printer at $500 (computed at $42 per month)
$22,029	SUBTOTAL COST PER YEAR
$ 30	SUBTOTAL COST PER STUDENT

[a]Hardware only, exclusive of software. N.B.: Costs of hardware as of May 1984

Source: Levin, Glass, and Meister (1984)

TABLE 5-1B. COMPUTER ASSISTED INSTRUCTION *MINICOMPUTER SYSTEM* HARDWARE AND MAINTENANCE ONLY

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

Annual Cost	Ingredient
	EQUIPMENT (Hardware only)
$ 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	1 dot matrix (120 cps) printer at $900, annualized at 10% interest over 6 years[a]
1,102[a]	Installation at $4,800, annualized at 10% interest over 6 years (includes CPU at $1,500, terminals at $3,200, and printer at $100)[a]
	OTHER (Maintenance only)
9,720	Maintenance (includes CPU at $3,600, terminals at $5,760, and printer at $360)
$20,860	SUBTOTAL COST PER YEAR
$ 28	SUBTOTAL COST PER STUDENT

[a] Hardware only, exclusive of software. N.B.: Costs of hardware quoted by Computer Curriculum Corporation as of 3/16/84.

Source: Levin, Glass, and Meister (1984)

TABLE 5-2. 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

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Source: Levin. 1985. Table 2

TABLE 5-3. 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

Source: Levin, 1985, Table 3.

TABLE 5-4. 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

Source: Levin, 1985, Table 4

TABLE 5-5. COST PER STUDENT FOR CAI INTERVENTIONS

Project	Actual Cost per Student	Full Utilization Cost per Student
Asbury Park	$382	$100
Chelmsford	164	113
Kindersley	98	67
Lafayette	334	305
Newark		
Teacher	431	232
Aide	273	150
Omaha	78	77
Pasco	375	242
Salt Lake City	217	166
Average	$294	$182

Source: Levin, Leitner, and Meister, 1986, Table 3.

TABLE 5-6. COST-EFFECTIVENESS ANALYSIS OF FOUR CCC INTERVENTIONS AT PRIMARY LEVEL

	Effect Size		Actual Cost			Fully Utilized Cost		
			Cost per	CE		Cost per	CE	
	Math	Read.	Stud.	M	R	Stud.	M	R
Chelmsford	.09	.36	$164	.05	.23	$113	.08	.33
Lafayette	.23	-	334	.07	-	305	.08	-
Newark	.42	.15	431	.10	.04	232	.18	.07
Pasco	.23	-	375	.06	-	242	.10	-
Average	.24	.26	$326	.07	.13	$223	.11	.20
Los Angeles Experiment	.12	.23	$119	.10	.19	$119	.10	.19

Source: Levin, Leitner, and Meister, 1986, Table 6.

Chapter VI

WILL COMPUTERS IN EDUCATION MAKE A DIFFERENCE?

Microelectronic technology makes vastly more information available and makes it available more quickly and economically. Through its impact on telecommunications, it reduces economic distances on a global scale. It also increasingly internationalizes information and the way that we communicate with each other.

Whether this is good or bad for the majority of the world's people is a very important issue, but is not going to be resolved in any society by attempting to halt the growth of microelectronic production and application. The new technology, as were previous technologies, will be a significant element in economic and social change everywhere. But its impact could vary considerably: it will be shaped by a process of political bargaining between nations and by affected groups within nations. That bargaining process will be, in turn, affected by the diffusion of knowledge and extensiveness of debate *about* the impact that the new technology is having and the key variables shaping that impact.

Computer education (as a means of instruction and object of instruction) is part and parcel of the new technology, and, at the same time, it represents access to understanding computers and participating in different kinds of work involving computers. Computers in education may also affect the way people think about computers and *who* gets involved in the bargaining process over their economic and social applications. Computers in schools may therefore be important in the overall changes taking place in national and international economic and social policy.

In this study we have attempted to assess the possible impacts that computers in education have on skill development for the labor market and on educational outcomes. Most of the knowledge accumulated on these effects is in the developed countries, with their longer history of applications of computer technology to education. Much of the detailed analysis is for the United States. There are obvious differences between the contexts for computer education in developing and developed countries. But the results *are* suggestive. And they also indicate the possibility of undertaking serious evaluations of these impacts.

In this chapter we summarize the results of current research and indicate directions for carrying it forward for policy decisions in countries contemplating investments in computers for education. We conclude that the impact of computers is controversial enough that such research should be carried out before any large scale investment is committed. Furthermore, even if computers are to be used in education, the *way* they are used should depend primarily on their effectiveness in achieving well-defined objectives. These objectives may vary substantially from society to society. Evaluations must therefore be tailored to specific situations.

HUMAN RESOURCES AND COMPUTER SKILLS

The empirical research in the United States suggests that even with the rapid growth of the microelectronics industry and industries that are tied to microelectronics. such as computer business services, the number of jobs requiring higher levels of computer training -- those normally associated with programming skills and a more intimate knowledge of how computers work --are growing rapidly, but will continue to represent only a small fraction of the total new jobs in the economy for a long time to come. Further, although in the United States and other developed countries jobs working *with* computers or machines with computerized elements already represent a much higher fraction of all jobs (in the U.S., some, like Yourdon (1986), have argued that by the year 2000, 80 percent of jobs will require computer literacy), most of these jobs require a minimal amount of computer-related training and this training can be and is being provided on the job. The importance of "computer literacy" training in schools for this vast majority of computer-related jobs is therefore questionable, although no study has been undertaken until now that relates computer access in school to income or the type of job taken in the labor force. Thus no definitive claims can be made as to the importance of computer literacy in job access or productivity.

These results should be taken seriously in the United States and in other countries. but they also should be interpreted carefully. On the one hand, whereas the results show clearly that the spread of computer technology will *not* produce a mass of high technology occupations requiring high levels of programming and other computer skills. there is little doubt from the experience of the developed and newly-industrializing countries, that an economy wishing to participate meaningfully in microelectronic production and its application to other industries will have to develop significant numbers of specialists with computer programming and engineering skills. To develop and train these specialists will require a much larger number of young people to have access to computers in high schools and perhaps in middle schools. In developing countries it will also require more time and better training methods than are currently being used in developed countries because of the *lack* of availability of computers outside of schools. It is precisely outside of schools in developed countries that the most highly skilled computer programmers are developing *themselves*. But this computer-rich context of countries such as the United States is not the context of most developing countries, even the more developed ones that have already entered the microelectronics sweepstakes.

On the other hand, the lack of computers in the society at large also impacts decisions about computer literacy. An argument can be made that in lower income societies with relatively few computers available to the population through private ownership, the only possible way to develop a computer-literate labor force (even when the levels of computer literacy required for many of the new jobs are quite low by developed country standards) is to make computers available in schools. In that interpretation of the results for the U.S., the reason that it is so relatively easy to train people for most jobs using computers is that the general *presence* of computers in society makes almost all young people and many adults necessarily more computer literate than in societies that have relatively few computers. Nevertheless, even if that is the case, the counter-argument can be made that software will tend to be increasingly "user-friendly," so much so that almost anyone, even those totally unfamiliar with computers can be easily and quickly trained to use them. This is clearly the trend. Furthermore, it appear that the kinds of skills associated with the somewhat more sophisticated "computer-literacy" uses of computers that are general "skill" training in the computer applications -- word-processing, spreadsheets, feeding and extracting information, and factory applications -- include a much more important element of traditional skills, such as typing, accuracy, working with complex machines, and statistical and math skills. These are much more the product of overall quality in the educational and job-training system than in the availability of computer education. It can also be argued, given the trend toward simpler software, that the principal reason for locating the production of goods and services that employ computers in a particular place is not necessarily the computer skills of the labor force there, but the level of wages relative to the level of education, irrespective of computer training.

All this suggests that the use of computers in high schools and universities to develop the high-skilled engineers and technicians needed for high-tech production and certain aspects of high-tech microelectronic applications may make sense as part of a strategy of ensuring some meaningful participation in the growth of new forms of industrialization, commerce, and services. Such participation will, however, take much more than just making available programming courses for high school students. It will require secondary and university education much more geared to physical sciences, mathematics, and their applications. It will also take the development of clever industrial and social policies, including export promotion and appropriate macroeconomic measures consistent with changing global trade and investment patterns.

The argument for investing in computer education for computer literacy is much less clear, unless early computer literacy is seen as a means of promoting later (high school) involvement in more sophisticated programming courses. For most countries, computer literacy may be an expensive indulgence with rather low pay-offs. It can be argued that in low-income countries with few computers easily accessible to the public at large or even in the workplace there is a need to familiarize young people with computers in the schools as part of their general preparation for an information future, a preparation that they will not gain elsewhere. But is there really such a need? Will computer-literate youth bring computer industries or computer applications to low-income economies, or will other factors (low wages, relatively high levels of general education and industrial training, and competent managers) be much more important?

These are all still speculations, however, until more research is conducted on the relationship between computer education and the pay-offs in the labor market to those who get different levels of computer access. In many countries, such studies will take some years to conclude, since there are relatively few jobs requiring any computer education, in school or on the job. But a wide range of examples, from Mexico to Brazil to Korea to Taiwan to India can provide comparative results in the context of a variety of experiences. Since computers are being incorporated differentially into these different societies, such research should also provide the basis for analyzing different ways to teach computer skills in various contexts.

COMPUTER MEDIATED LEARNING AND EDUCATIONAL POLICY

Although the evaluations of the social and economic impacts of computer use in education have only begun recently, there have now been two decades of research on the effects of computer-mediated instruction. In large part this is the outcome of influence exerted by computer visionaries like Papert fascinated with the implications of computer-human interaction for changing the learning environment, and the more "practical" "technology in the classroom" types like Suppes who saw computers as an effective way to raise learning curves of standard subjects such as math and language skills.

The evaluations that have predominated have been of computer-assisted instruction (CAI), where reading and math achievement are the outcome measures. According to our review, these studies show a number of significant results: (1) drill-and-practice sessions of limited duration over an extended period of time do increase reading and math scores of primary school students; (2) where achievement gains of CAI relative to other forms of instruction have been the focus of research, CAI proves to be an effective supplement to classroom teaching; (3) in comparisons of different modes of CAI use, there appears to be a slightly greater cognitive gain at the high school level when the computer acts as a complete substitute for teacher, textbook, etc. than when the computer acts as a supplement, but not at the primary level, where the opposite is the case; (4) there appear to be greater gains for those pupil with lower academic skills than for those with higher (which implies that the computers may serve as an "equalizer" of learning possibilities for disadvantaged students); (5) computers are not particularly better at raising math over reading scores -- some studies show larger increases in math scores and others, in reading scores; (6) there appears to be a declining effect of CAI, the longer the length of instruction; and (7) there seems to be no clear indication which aspect of CAI most directly affects these gains, i.e. software design, intensity of contact, external reinforcements of CAI material, and so on.

But there have also been evaluations in the U.S. of LOGO (problem-solving) applications. Unlike the CAI evaluations, which show a clear trend, the LOGO studies show mixed results. Some suggest significant gains in problem-solving skills, including gains in divergent and reflective thinking. But a major two-year study of LOGO found no significant effect on cognitive skills. Neither do any studies sustain Papert's claim that learning with LOGO-type programs will create new conceptual skills in children.

Research on the motivational effects of computers on learning is even more limited than on its cognitive effects, but available recent studies (again, in the U.S.) suggest that several aspects of modern tutorial software, particularly the fantasy element, could make the subject matter intrinsically more interesting and hence could increase learning. Furthermore, other studies indicate that motivation to learn particular subjects is increased in the CAI environment.

Does this mean that countries, states, and school districts making the decision to put computers in schools for general instruction should go for drill-and-practice and supplemental computer applications and avoid more teacher-independent, problem-solving software? Although this is the direction suggested by evaluations to date, there are enough problems with such evaluations to merit both caution and considerably more research, particularly in non-U.S. settings.

The fact that most LOGO evaluations have been carried out in the U.S. setting may have prejudiced results of LOGO assessments: since curriculum and teacher training in the U.S. is drill and practice-oriented, problem-solving CAI should probably be evaluated in a curricular setting that stresses such an approach (for example, in a European-type educational system). Furthermore, it is easier to design and implement good drill and practice software than problem-solving software, although those teachers who are best prepared to work with computers in the schools appear to prefer the latter to the former.

What seems to be lacking in all of these studies is an underlying theory of learning that can explain why or why not computers will enhance learning. Papert's seminal work is as yet unsupported by firm data. Fabulous claims of computers' effect on the educational process have not been observed in the real world. Yet this may be true because of the way computers are being used in the educational process and because learning with computers is just at the beginning of its applications. Such effects may take a generation or two to be felt. What educational technology may do is to provide a less "restricted world," a world in which more cognitively significant experiences are available.

What about CAI itself? Are the results convincing that CAI will yield high gains in language and math skills everywhere? Are the CAI results universal or only relevant in an educational system which stresses learning through repetition? Again, the fact that the studies are also highly concentrated in a particular setting suggests caution in projecting the results to other countries. Little information exists about the relative effectiveness of different kinds of applications in education in different learning settings.

Thus, in all areas of exploration concerning the educational effects of computers, cultural context requires greater attention. The learning styles that characterize education both inside and outside of schools may have as much to do with what students learn from computers as software features. The definitions of learning implicit in instruments used to measure it may not be appropriate across cultures. Among all of the areas of research on computers and education, computer effects on learning may be the least generalizable to different social and cultural contexts.

COST-EFFECTIVENESS OF COMPUTERS IN EDUCATION

Nevertheless, in the United States, CAI applications look promising to improve learning speed, and to improve the relative learning speed of disadvantaged children. Does this mean that schools should invest more heavily in computers? To make this decision, we looked at the *cost-effectiveness* of CAI, in addition to the effects on learning. Cost-effectiveness tells us how computer-assisted instruction compares to other interventions not only in terms of effects but in terms of relative costs.

In this comparison, CAI appears to do well, but not as well as peer-tutoring. In terms of cost-effectiveness, then, using computers as a teaching supplement may produce better results per $100 of investment than reducing class size or increasing instructional time. But peer-tutoring under present conditions of computer usage is much more cost-effective than any of these interventions. Given these results, and focusing on the single objective of improving reading and math achievement, schools would do well to increase peer tutoring and reduce CAI.

There are several caveats to these results. First, CAI may have more potential to improve its cost-effectiveness in the future than other interventions because of improved software, more effective applications, and so forth. Improvement potential may be much smaller with simpler technologies. Second, there are other objectives to technologies than just raising learning speed: in the case of computers, CAI also introduces pupils to the computers themselves and may end up creating both interest and skills that carry over into the job market. Peer tutoring, on the other hand, may create greater interest in learning and schooling than other technologies.

Furthermore, these results apply to the United States. In other countries, costs of computer education relative to the cost of other interventions may be very different than in the U.S. The skilled labor needed to service and manage computer education interventions may be in much shorter supply; educational software in the local language difficult to find; and teachers even less prepared to use computers effectively in the classroom. Other interventions not included in the U.S. comparisons, such as textbooks or educational radio, may be very relevant in low income developing countries, whereas they are not relevant to a developed country educational setting. Smaller classroom size (since the number of pupils per teacher in many countries is considerably higher than in the typical U.S. classroom) may also have a greater effect per unit of cost than computers.

The meaning of all this is that cost-effectiveness results are very sensitive to educational/economic settings. Even in the United States, there is some controversy over whether present cost-effectiveness ratios reflect what they *might* be under changing software and other conditions for CAI. If we try to apply these U.S. results to decision-making in a totally different resource-availability situation, the error possibilities would increase accordingly.

Each country should therefore undertake its own cost-effectiveness studies and use those studies to make its particular educational technology decisions. At present these studies are essentially non-existent.

WHERE DOES THIS LEAVE US?

Computers in U.S. schools make sense in terms of teaching programming skills to a broad base of pupils in middle school and even primary school with the intention of stimulating interest in advancing to higher levels of programming and programming applications to science and math. Computers probably also make sense in teaching vocational skills such as word and data processing in high school. The arguments for CAI and general computer literacy are less persuasive, particularly in terms of cost-effectiveness, but in the CAI case could become more persuasive if ways are found for CAI to make a larger impact on learning for the same or lower cost. With improved software and improved teacher preparation, effects could rise.

None of these conclusions (tentative as they are) may hold for other countries, although we suspect that predictions can be made about the value of educational computers in developing countries in terms of their labor market applications by knowing something about actual and planned changes in the structure of industry and trade in a given country. Much less can be said about the learning effects of computers in other countries, nor about the type of approach to learning (CAI versus LOGO) which would be most effective. Until much more research is undertaken and its results available and assessed, decisions about bringing computers into the schools to prepare youth for an uncertain future will be made for many of the wrong reasons.

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