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EDUCATION AND COMPUTERS: VISION AND REALITY

by Martin Carnoy
Hugh Daley
Liza Loop

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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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

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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.

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.

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

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

practitioners in spite of the research community's inability to demonstrate a measurable 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 sufficient equipment for this purpose. In some U.S. high schools that do 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 one of several printers. If the student's activity results in data the teacher is to review at a later time, the data can be copied into the student's file on the hard disk or onto a floppy disk in the microcomputer.

Wide-Area Networks. Computer networks that cover a larger geographical area use telephone or microwave links to carry signals from one computer to another. The machine at the user's location is usually referred to as the "terminal" while the machine at the other end of the telephone line is called the "host computer." Two users at two terminals on a network can send messages to each other in a conversational style sometimes called "chat" or in a time delayed style called "electronic mail." When chatting, the host computer passes the message immediately to the addressee's terminal. For electronic mail, the host computer serves as a "mailbox" and holds the message until the recipient requests that it be delivered to his or her terminal. A "dumb terminal" acts as a keyboard and screen or printer to the host computer but is not a computer in itself. An "intelligent terminal" or a microcomputer running an intelligent terminal program can receive text, programs, and sometimes pictures in electronic form. These can be used even after disconnecting from the host computer.

Computer networking has been used by businesses for decades, and timesharing (many dumb terminals sharing a single host computer) was the usual form of educational computing during the 60s and early 70s. Stand-alone microcomputers were tried in the late 70s and early 80s but their expense and the need for even more expensive, high-quality peripherals has spurred the introduction of local area networks into schools and colleges. Once on a network, users discover the advantages of electronic, interpersonal communication.

Network-based Educational Projects. Within the context of improved communications, several interesting and innovative experiments are currently being undertaken in the United States. The National Simulation in International Studies and Translation project (NSIST) organized by the University of Maryland and University of California, Santa Barbara, makes use of networking in both a multi-university (national and international) and cross-disciplinary educational project involving large scale human simulations. Students in international relations and advanced foreign language students (as translators) participate in the simulation of conducting diplomatic affairs. A scenario is set up (e.g. the Arab-Israeli conflict in the post-Camp David and post-Lebanon war period) and various teams made up of students from the nations involved have to negotiate a settlement. The computer is used as a message clearing house. The country-team messages are originated by native speakers and each country team has a team of translators for the incoming messages. When country teams are large (e.g. one whole class of 20 students), these are broken down into units, such as military, economic, or domestic, and each unit may have its own team of translators. Provisions for the participation of up to 24 U.S. universities and two foreign universities (The University of Wasada, Tokyo, and the Hebrew University, Jerusalem) have been made.

Telelearning also falls within the context of improved communications through the use of educational computer networking. At least four universities in the U.S. (IFG, 1985) as well as the Open University in the United Kingdom permit college students to "attend" courses via remote terminals. The San Francisco-based Electronic University (Lockwood, 1984; Telelearning Systems, 1986-87) offers more that 250 college courses by computer and plans to market its networking software to other organizations (see also Meeks, 1987).

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.

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).[3]

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[3] 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

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 Germany and Japan, there is a serious questioning of the need to invest massively in computer literacy in already highly computerized societies (Carnoy & Loop, 1986).

The most frequent use of computers in primary and general (lower) secondary school is in computer-assisted instruction (CAI) -- as an aid in teaching general academic subjects (mathematics, science, and languages) -- largely through drill and practice. Whereas it was originally though that computers and software could provide an inexpensive substitute for teacher skills and that pupils would learn to use the computers by themselves (i.e., that microcomputers are inherently "children-friendly"), it has been found that to be successful, computer-assisted instruction requires considerable teacher-training and that most children require considerable assistance in learning to use computers. Thus, like other curricula, CAI also tends to be teacher-centered as well as software-centered. Some teacher reluctance to engage in CAI programs, the lack of suitable software, and the limited number of computers available in schools, has caused some countries (such as Australia, Canada, and the U.K.) as well as many schools within more decentralized systems, such as in the U.S., to gradually relinquish the emphasis on CAI applications and to teach, instead, data processing using utility software (word processing, file management, databases, and tabulators).

The decision to use drill-and-practice rather than problem-solving approaches in a particular country depends very much on the dominant type of curriculum used. The dominance of drill-and-practice in the U.S. is in large part a function of U.S. primary school curriculum; similarly, the emphasis placed on LOGO-based, problem-solving approaches in English- or French-based educational systems is also consistent with curriculum needs. Teachers are likely to choose the computer application that best fits their understanding and their curricular requirements.

HOW IS EDUCATIONAL COMPUTER USE DISTRIBUTED?

The distribution of computers in education among and within countries has been of concern to those who view differential access as indicative of future distributions of world production of information and of differential access high quality jobs in the information economy. Yet the debate has not reached deeply into the computer education literature because much of the data on access is anecdotal and the effects of unequal access to computers on learning, jobs, and national development not researched sufficiently to point clearly in any particular direction. Thus, our discussion here is

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Chile).

largely suggestive and speculative. Nevertheless, some trends do emerge, and they may have important distributional implications.

Outside of the developed countries, there is presently extremely limited access to computers in schools (UNESCO, 1986). Schools within countries that have computers are not at all equipped to the same extent, creating problems of differential access for different groups of pupils (among those who even go to school). Primary schools are much less equipped than secondary schools, implying, in most developing countries, no access at all for most of those who attend schools. Private schools are generally equipped far better than public schools, and certain categories of public secondary schools, better than others. In those countries that have emphasized computers in education for preparing future technicians, programmers, scientists, and engineers, computers have been concentrated in secondary and university courses catering to these courses of study. But things appear to be changing quickly: in the near future, computers are likely to be brought into schools in increasing numbers even in the poorest countries, 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]

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 1 high schools, for example, experienced insignificant, almost static, growth in computer programming classes (7 percent), during the 1978-82 time period, while non-Title 1 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.

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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 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.

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 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]

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

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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).

[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.*

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]

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.

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

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.

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

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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.

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.

APPENDIX TO CHAPTER II

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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).