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Chapter 5

Computers and Education: A Cultural Constructivist Perspective

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The general topic of the use of computers in education has not been systematically dealt with in the *Review of Research in Education*, although some specific aspects of it have been touched on (e.g., Sherrie Gott's chapter on apprenticeship and intelligent tutoring systems in Volume 15). Since the field is so vast, no review could do justice to it; thus, we must circumscribe the research we are reviewing to a manageable portion.

Our major restriction is that we concentrate on Grades K–12 with an emphasis on late elementary school and early secondary school ages, including higher levels of the education system only in a few cases to illustrate a point. Within this still-vast field we select some research that has been widely disseminated, and therefore characterizes the field, and some research that, in our view, holds special promise for the future. Also, we come to this topic from a particular theoretical perspective, which acts as a further filter on the topics discussed.

We call that perspective *cultural constructivism*. The basic idea of this approach can be grasped most readily by contrasting it with Piagetian constructivism.

Piaget is justifiably famous for demonstrating the need to consider children to be constructors of their own development through their actions. By contrast, a *cultural constructivist* approach assumes not only an active child but an equally active and usually more powerful adult in interaction (we are speaking of educational settings). Moreover, cultural constructivism emphasizes that all human activity is mediated by cultural artifacts, which themselves have been constructed over the course of human history.

The general framework of this approach is derived from the axioms of the cultural-historical school of psychology, which asserts that the unique character of human activity is that it is mediated through socially constituted, and historically developing, systems of artifacts (see Wertsch, 1985, for a general treatment).

From this perspective, the historically conditioned forms of activity mediated through computers must be studied for the qualitatively distinctive forms of interaction that these artifacts afford and the social arrangements that they help to constitute. Moreover, one is encouraged to seek explanation of current uses of computers in terms of the history of the technology and the social practices that the technology mediates; one needs to consider the "effects" of interacting in this medium not only as they are refracted through transfer tests or in local activity systems (such as classroom lessons) but also in the entire system of social relations of which they are a part.

We begin to construct such a framework for computer use in education by sketching the historical context in which computer technology came to prominence and the perceived state of American education at the time it did so. We begin by sketching the 20th-century origins of computing in the military establishment. These origins are important to note not only for historical reasons but because the military remains the most important organization promoting research in computer-based education. We then look at various characterizations of the pedagogical use of computers in civilian education, concentrating primarily on the K–12 component.

Our account of these pedagogical factors is broadly cast and includes consideration of patterns of computer provision and of teacher education. We trace some of the leading trends in the use of computers for educational purposes over the past few years (those we feel to be most relevant to actual classroom practice).

After an all-too-brief excursion into the broader contemporary social context of computer use in education highlighted by recent research on gender and ethnicity, we discuss some projects that embed computer use in education in wider social contexts and conclude with a discussion of the evaluation issues in computer education.

THE CULTURAL-HISTORICAL CONTEXT OF COMPUTER USE IN EDUCATION

Computers and our conception of computers (if we may be allowed a commonsense dualism) were both constituted by and helped to constitute changes in the world between the mid-1940s and 1990. In this process, they were touted both as the positive agent of an optimistic vision of the future and excoriated as the negative agent of a grimmer version of that future (Evans, 1982; Stonier, 1983; Weiner, 1950/1989).

In the years before World War II, the word *computer* referred to a person who computed numbers. During the war, as the technology of ballistics developed and as encoding devices became more sophisticated, there was an urgent need to calculate enormously complex equations. As Winston (1986) put it, ENIAC (the first practical digital computer) was ''still, in essence, a calculator designed to work out ballistic firing tables'' (p. 137).

The great rapidity of the calculating machine soon displaced the (human) computer, whose work was restricted to programming input and using output. The spread of modern computers far beyond the confines of the military in recent decades somewhat masks the continued influence of its origins through military-sponsored research. Joseph Weizenbaum (1976, p. 568) has commented that ''the computer in its modern form was born from the womb of the military.'' A good deal of historical research has supported his conclusion (P. Edwards, 1985, 1986, 1988; Noble, 1989; Slater, 1990; Winston, 1986).

Many of the developments in educational uses of computers we will discuss in this chapter have their origins in research on creating man-machine systems for military purposes and in improving military training, an origin that continues to shape the very structure of those educational practices. Whether one thinks this state of affairs is good or bad is a matter of personal values and estimation of effects. Our own view is that one needs to be suspicious of educational technology that embodies presupposed fixed tasks and goals and a restricted range of social arrangements of a top-down, authoritarian nature.

The development of computer technology also bears an interesting relationship to Americans' views of their educational system and to their views of the utility and importance of the ''computer revolution'' within and outside the education system. Although alarm has been expressed about the quality of education in American schools throughout this century, the period just following World War II found the United States a dominant world power whose technological achievements were a matter of pride and emulation. So secure did matters seem in the early 1950s that J. K. Galbraith could celebrate the prospect of a permanent freedom from want in his highly publicized book *The Affluent Society* (1958). The country seemed to support his optimistic view by responding with a series of educational reforms that implemented, more or less, the vision of progressive educationalists following in the tradition of John Dewey (see Cremin, 1976, for a review and discussion).

Activity-based curricula became the order of the day. Classrooms were reorganized to facilitate group and project work. A ''checklist'' focus on assessing achievement was displaced by a concentration on outcomes derived from integrative studies illustrating a range of curriculum achievements. However, while the evidence shows that these activity-based curricula (many of which were highly technological in character) were successful as first implemented, follow-up surveys indicate that once external funding was withdrawn, their use declined. At present, activity-centered curricula continue to be found in less than 10% of classrooms in the United States (see Kyle, 1984, for reviews and discussions of these efforts).

As America leapt ahead of the Soviet Union in the competition for dominance in space exploration during the 1960s, U.S. attention turned from concern to maintain high-powered education of the nation's middle classes to address those portions of the population not included among the affluent as part of a highly publicized "war against poverty."

Education was seen as the key to breaking the "cycle of poverty" so that all could partake of the affluent life. It is no secret that although many children benefited from the improved health care and nutritional services provided by Project Head Start, the "war on poverty" was most decidedly not won and the educational achievements of poor, minority-group children have continued to remain distressingly low (Muenshaw, 1980; Payne, 1973; Washington, 1987).

While this situation evoked and continues to evoke concern, the 1960s emphasis on eradicating economic injustice inside the United States was soon displaced by international concern evoked by our former World War II enemies, Japan and Germany. In recent decades, one has heard frequently the rhetoric so pithily captured by the title of the report of the National Commission on Excellence in Education (1983), *A Nation at Risk: The Imperative for Educational Reform*. When compared with the achievement of any number of economic competitors, American children continue to perform poorly in "basic" school subjects, especially those associated with the trinity of mathematics, science, and technology, upon which the United States' economic well-being is assumed to rest (see Stevenson, Lee, & Stigler, 1986; Walberg, Harnisch, & Tsai, 1984). Moreover, our achievements, such as they are, are very unevenly distributed.

At the same time that alarm was being expressed over comparative achievement levels in the schools, the American business community was distressed about the ability of school leavers to fill even entry-level jobs adequately. As various sectors of the American economy were eroded by foreign competition, industry began to get involved in education. Whereas the common wisdom in the 1970s had been that modern technology would simply *deskill* the work of lower and middle-level workers, by the 1980s it began to appear that highly educated workers were needed to run high-technology machinery and that such workers were in increasing demand (Sherman, 1985).

The issue of whether the amount of education was insufficient or the kind of education was inappropriate as preparation for "the average worker" still remains under dispute: Between 1976 and 1988 occupational groups that had above-average educational attainments grew by 51%, while those where low levels of educational achievement dominated grew by 19% (Bailey, 1989). In addition, skill levels demanded within occupational groups rose, especially on workers with low and average educational achievements.

There have been a variety of responses to this situation, including various forms of "back to basics" movements within the school curriculum and intensification of efforts by industry and business to upgrade the education and training of their employees. Recently, it has been estimated that U.S. firms spend $30 billion annually on formal training, a figure that is manifestly inadequate to the demand and is likely to grow (Commission on Workforce Quality and Labor Market Efficiency, 1989).

However important such job-related training may be, it is almost certainly not going to decrease the importance of education. In fact, some observers claim that

> increasingly workers' positions in the labor market are determined prior to their entry into the labor market, in the course of their access to the vocational and higher educational systems. . . . The vocational and higher educational systems will need to undergo fundamental changes if they are to respond to these new pressures. (Noyelle, 1985)

When we combine these considerations with projected increases in the intensity of economic competition, it is easy to see why there is cause for concern. By the same token, it is easy to see why so many people are attracted to the use of computers as a means of extracting us from a difficult situation; computers seem to promise a technological "quick fix," a relatively cheap, clean, and unproblematic solution to what we believe to be long-term, expensive, and dirty problems (Kerr, 1991).

Given the record of past technology-driven reforms, we approach the question of computer use as a solution to educational problems with some skepticism. As Cuban (1986) has recently warned, the education system will absorb each successive quick fix offered by technology and restore the status quo. This view is supported by recent studies conducted by Rosenberg (1991) of the notion of "computer literacy" as both making irrelevant promises in terms of the economic situation and failing to deliver on those promises, and the reactions to that work by computer educators.

Cuban points out that in the early phases, at least, the introduction of computer technology in the schools is recapitulating patterns of adoption of film and radio, two media whose transformational potential for education was announced in almost precisely the same terms as computer-led transformations in schooling are announced today. Consider, for example, the following claim:

> The central and dominant aim of education by [computers] is to bring the world to the classroom, to make universally available the services of the finest teachers. . . . The time

may come when a [computer] will be as common in a classroom as a blackboard. [Computer] instruction will be integrated into school life as an accepted educational medium. (Cuban, 1986, p. 19)

Visions of this kind are encountered so often with respect to computers in school that one must pause and think about the fact that this particular claim was written in 1932: The medium in question was radio!

Cuban's work reminds us that one of the few firm laws concerning the effects of introducing a new technology is the tendency of the social system to retain current goals and social organizations (and seek to achieve old goals more efficiently). To be successful as an agent of change (*re*-form), technologically based strategies should be based in a self-conscious effort to construct a social environment with a new morphology of interpersonal communication. It follows that there is a fundamental contradiction between the education system's conservative tendency to restore the status quo in response to each new technological innovation and the intended and unintended consequences of that innovation with respect to the goals of activities to be realized in the classroom (Cuban, 1986). We believe this to be especially significant in attempts to use computers as an agent of change in education, although the record thus far provides only meager justification for optimism.

THE PEDAGOGICAL CONTEXT OF EDUCATIONAL COMPUTING

Because our perspective highlights the importance of cultural and social factors as determinants of computer-mediated classroom practice, it also emphasizes the "close-in" components of the educational system. Curriculum design, building organization, teacher preparation, and their histories all profoundly affect the realization of the potential of the computer in the classroom.

First we look at the issues of computer literacy, computer competence, and computer programming, then we explore some applications of computing to education from a curriculum/subject perspective. The curriculum areas that we choose to highlight are science, English, and mathematics. (We bypass social studies because Thornburg and Pea [1991] have analyzed the synthesis of instructional technologies and educational culture in the context of social studies teaching from a perspective similar to our own.)

Our selection, though partial, serves to highlight the variety of approaches possible for computer use in the classroom. All but art are also presently the focus of debate on how to make a national assessment of progress toward nationally promulgated educational goals.

In examining this range of subjects, we draw on the characterization of various "modes" of human/computer interaction, developed for the purposes of comparative study by Makrakis (1988). Makrakis proposes, as a compromise between the various views of the computer as a device for individualized instruction and as a medium of interaction, that one should attend to no less than eight distinct "modes of delivery and interaction":

> It would be more practical to consider eight modes of delivery and interaction: (1) drill and practice; (2) tutorial; (3) instructional games; (4) simulation; (5) problem solving; (6) spreadsheet; (7) word processing; and (8) database management-processing. These modes have been placed in a hierarchical order from low to high according to their levels of cognitive/mental thinking and degree of learner/computer interaction. *It is of particular importance to note that any computer program may explore more than one of these modes*. A tutorial mode, for example, formally includes drill-and-practice exercises. Likewise, instructional games and simulations may be incorporated into problem-solving activities. (pp. 12–13) [italics added]

In our examination of the application of computing to English and mathematics, we concentrate on drill-and-practice as a historically significant approach, giving somewhat less space to the other modes of interaction.

When considering art and science, we look at some approaches that can perhaps best be characterized as "modeling and simulation." But first we begin with a consideration of computing activities as curriculum content.

Computer Literacy and Computer Competence

With advances in computer technology and its spread into a variety of social spheres, educators began to focus on the need to train new generations of students to program such devices for a variety of purposes, and the concept of computer literacy was born. The earliest reference to computer literacy that we have been able to find occurred in an article by John Nevison about the ways in which involvement with computers was being integrated into the curriculum at Dartmouth College in the 1970s. Nevison noted that the ability to write computer programs was becoming part of the assumed foundation of a liberal education.

> Because of the widespread use of elementary computing skill, there should be an appropriate term for this skill. It should suggest an acquaintance with the rudiments of computer programming, much as the term literacy connotes a familiarity with the fundamentals of reading and writing, and it should have a precise definition that all can agree on. It is reasonable to suggest that a person who has written a computer program should be called literate in computing. (Nevison, 1976, p. 401)

Adopting a rather narrow notion of literacy as mastery of the systems of symbol manipulation, one finds that during the late 1970s and early 1980s debates over computer literacy focused on the extent to which students need to be able to work with hexadecimal and binary number systems and to understand the principles of hardware construction. Perhaps the core conception of the pedagogical goals of computer use in schools at the time was provided by Arthur Leuhmann, who was quoted as asserting:

> One who is truly computer literate must be able to "do computing"—to conceptualize problems algorithmically, to represent them in the syntax of a computer language, to identify conceptual "bugs," and to express computational ideas clearly, concisely, and with a degree of organization and readability. (Douglas, 1980, p. 18)

During the 1980s one begins to see a shift in the terms of this discussion. With the advent of relatively inexpensive microprocessors, the dominant image of the computer as a machine driven by a card with rectangular holes punched in it is replaced by that of a microcomputer with a munched-upon rainbow apple on its screen.

It is not that the "traditional" emphasis on programming and learning to use quantifiable algorithms disappears. Rather, the advent of personal microcomputers, for which off-the-shelf applications programs were soon available, brought about a shift in emphasis among educators, researchers, and commentators. Instead of focusing on basic programming and engineering skills, computer literacy came to be seen as the ability to choose appropriate software applications and to modify them if necessary (but not at the level of the source program). Significantly, these applications began to extend beyond computing (understood as calculation) to word processing, that is, literacy activities of a more traditional kind, modified to take advantage of the microprocessor as medium.

The availability of the microprocessor also facilitated the development of computing as an entertainment medium, in the form of arcade-style games, which enjoyed extensive popularity and were later appropriated as the templates for "educational" games, which used the same style of human-computer interface for "less-trivial" pursuits.

With the addition of word processing to number manipulation, another significant element was brought to popular discussions of computer literacy—the need for an ability to use computers as communication devices through which one could interact with other people as well as with databases of a variety of kinds (Kinzer, Sherwood, & Bransford, 1986; Trainor, 1984).

By the beginning of the 1980s the broadening capacity and availability of microcomputers and communication networks made it clear that the initial focus on computers as, literally, devices for making computations had been supplemented by a general conception of the computer as (potentially) a general purpose tool for the manipulation of information, as a medium for pursuing educational goals that have nothing intrinsically to do with computer programming, and as a source of entertainment.

Concomitantly, one began to encounter the notion that what one should seek educationally is "functional computer literacy," which Longstreet and Sorant (1985, p. 119) suggested must encompass "the ability to be flexible and to modify existing procedures to new hardware and software" (Chandler & Marcus, 1985; Stonier & Conlin, 1985).

Alongside these changing views of computer literacy (see Pryczak, 1990, for a collation of views about "minimal" skills), people were also developing notions of the computer as a conveyor of pedagogy, either directly (the computer taking a tutorial role) or indirectly (the computer as a tool and as a resource; Levin & Souviney, 1983). This variety of uses was captured by Taylor (1980), who spoke of computers as "tutors, tools and tutees."

The 1983 National Commission on Excellence in Education report, *A Nation at Risk*, was the first formal, national document to include a consideration of computer literacy as a component of the national profile of educational progress, alongside a review of the traditional "three Rs." *Computer Competence: The First National Assessment* (Martinez & Mead, 1988), based on 1985–1986 data, followed this up with a more detailed review of computer competence.

The transition from "computer literacy" to "computer competence" is not without significance. Indeed, the major findings of Martinez and Mead, the authors of the latter, Educational Testing Service report, are so significant to our ensuing analysis that we quote them in full.

> Several key findings emerge from this first national assessment of computer competence:
>
> Students generally had difficulty answering questions on the assessment, especially questions about computer applications and programming.
>
> The experiences of having used a computer, or studying computers in school, and of having a computer at home are positively related to computer competence.
>
> Most students like using computers and want greater access to them.
>
> Much learning of computers takes place outside of school and independent of formal instruction. Across demographic subgroups, the increased competence associated with having a computer at home is comparable to the advantage linked to studying and using computers at school. Students who study computers at school and have a computer at home are the most competent.
>
> Computers are seldom used in subject areas such as reading, math or science. Rather, the use of computers in schools is largely confined to computing classes.
>
> Males, in general, demonstrate a slightly higher level of computer competence than females.
>
> There are clear racial/ethnic differences in computer competence, favoring White students over Black and Hispanic students. These differences are present even between students who have comparable levels of experience, but the differences are accentuated by greater experience with computers among White students.

Other subgroup comparisons show an advantage for:
—students whose parents are college graduates
—students who attend non-public schools
—students who live in high socioeconomic metropolitan areas
—students who live in the Northeastern United States
These subgroups are most likely to have used a computer, to be studying computers at school, and to have a computer at home.

Many computer coordinators have minimal training in computer studies and rate themselves mediocre in their ability to use computers. (Martinez & Mead, 1988, pp. 5–6)

Many of these issues will be taken up in ensuing sections. Here we wish to comment on the notion of "computer competence" and the persistence of "ability to program" as a component of that competence. The National Assessment of Educational Progress (NAEP, 1985) report specified three areas as constituting computer competence: knowledge of computer technology, understanding of computer applications, and understanding of computer programming.

This is a much wider specification than the view of functional computer literacy specified by Longstreet and Sorant (1985) and others who argued that the important quality is the ability to apply computers to changing circumstances without a deep knowledge of the component parts or internal algorithms. The view implicit in the NAEP document, by contrast, is that now one *should* be able to recognize the functions of the various component devices and peripherals (and that by the 11th grade over 90% of those asked were able to do so).

In addition to these "knowledge" questions, students should also show skills in applying software to a task. Martinez and Mead (1988) report results from testing directed at the application of word processing, graphics, databases, and spreadsheets over Grades 3, 7, and 11. They report levels of success at Grade 11 for these four domains of 72.2%, 60.7%, 53.4%, and 31%, respectively (p. 20). They point out that these differentials might arise from frequency (better *in*frequency) of use.

The pattern of use is, of course, a reflection of a complex range of issues: Teacher preparation as a significant element of this kind of patterning will be taken up later.

Students were also asked about three programming languages—LOGO, BASIC, and Pascal—all designed primarily for educational circumstances (although Pascal plays a more definite role in "real" programming, its function as a language for education and training was an important element in its design). Programming performances reported were very low, never rising over 40% (Martinez & Mead, 1988, pp. 26–27).

Combining the various results, NAEP concluded with an estimate of computer competence over Grades 3, 7, and 11 in which "most students appeared to have difficulty answering the assessment questions. No grade averaged even 50% correct, and third graders were able to answer only a third of the questions correctly'' (p. 28).

Martinez and Mead (1988), quite correctly, note that perhaps the most important problem to be addressed is the continuing disagreement among educators about what should be taught about computers in American schools. This debate concerns the teaching of computing per se and the integration of computing in the curriculum.

One can see, in the different categories of results, that the desire to include programming as an element of computer competence has the effect of pulling down overall performance. Whereas the categories of ''knowledge about'' and ''how to apply'' computing can be clearly motivated in the classroom, and teachers can understand how to teach the ''knowledge about computers'' category fairly well, relatively few teachers, and even computer coordinators, are adequately prepared to teach the more subtle aspects of programming or are themselves competent to make effective use of authoring languages.

Computer Programming

Much research into computer use in education in recent years has focused on those situations in which ''the child is controlling the computer.'' The ''computer as tutee'' is conceived of as a ''protean'' object with potential to be applied to a whole range of problem domains. In some sense, the attention paid to students' abilities to manipulate the ''computer as tutee'' is a rehearsal of the original drive in computer literacy for programming competence not for its own sake but because of beliefs about the cognitive consequences of programming.

Rather than programming the original, underlying computer, however, the ''computer as tutee'' in the precollege curriculum is inevitably a computer under the control of an ''educational'' language environment. Most commonly, in the range of education we are concerned with, that environment is either the LOGO or BASIC programming language.

Examples can, of course, be found of experiments with the ''computer as tutee'' using a wide range of programming languages, including comparatively early and less sophisticated languages and more recent and complex approaches such as Prolog (Ennals, 1985). We have chosen, however, to concentrate on LOGO (as the computer language of the middle years of schooling) rather than engage in the debates about appropriate educational languages because the educational rationale is best articulated for this language and its use has been the subject of most research (Dyck & Trent, 1990; Pea & Kurland, 1984; Pea & Sheingold, 1987; Weir, 1987).

Miniprogramming

There is a class of programs that is sometimes used as a precursor to fuller implementations of LOGO or LOGO-like languages or cast in the guise of discovering and developing mathematical concepts or programming routines. For example, Pond (Sunburst Corporation) provides an environment in which children discover repeating patterns of lily pads. A notational system of directional arrow keys and numbers is used to instruct a frog to move according to an algorithm created to reflect the recursive pattern of lily pads in a given pond. The goal of the game is to move the frog from the beginning of the pond to the designated "magic" lily pad at the end of the pond. Students are given an opportunity to rehearse the required patterns by trials in which they can move the frog across the pond jump by jump. To move on through the program and to "win the game," however, they must commit themselves to inputting a complete sequence of instructions. The frog will follow the instructions and either succeed or fail in its mission of crossing the pond. The frog's moves are constructed in terms of patterns, such as "two right and three down": The child must construct the appropriate number/direction: number/direction pairings (Griffin, Belyaeva, & Soldatova, in press; Lemons, 1990). Whereas such programs are cast in terms of the teaching of mathematical principles, they also inter alia require the development of certain programming skills.

Programming: Gaining Mastery of Microworlds

Perhaps the most influential line of research on the instructional uses of computers, and one that enables a sharp break with the tradition of teacher-led lessons followed by drill-and-practice, is that led by Seymour Papert. By his introduction of a graphics element and a steerable turtle into the LOGO programming environment, he enabled students to approach programming through the "mini-programming with visual feedback" route outlined above. In his enormously influential book *Mindstorms* (1980), Papert presented a constructivist theory of learning and development and showed how LOGO, considered as a "microworld," could be used by children to construct a variety of interesting objects in various knowledge domains: geometry, music, art, and so on. Papert suggested that in addition to whatever domain-specific knowledge children accumulated, they would also accumulate powerful ideas about their own knowledge and learning process (often given the generic label "metacognitive" skills.) As he described the core idea:

> In Turtle geometry we create an environment in which the child's task is not to learn a set of formal rules but to develop sufficient insight into the way he moves in space to allow the transposition of this self-knowledge into programs that will cause a Turtle to move. (1980, p. 205)

Using Piaget as the major source of inspiration, Papert's claims about the intellectual consequences of creating objects through LOGO were grounded in notions about assimilation and accommodation that seemed to promise broad transfer, much in the character of a Piagetian stage. He suggested that the computers (in particular, as used by members of the Massachusetts Institute of Technology [MIT] Media Lab) permitted children to "concretize (and personalize) the formal" (p. 21).

Although he denied a technological determinist interpretation of "the effects of LOGO," his descriptions of the character of the social setting were sufficiently backgrounded that a number of tests of Papert's claims about LOGO were conducted using more or less controlled procedures, a conventional experimental group–control group experimental design, and various measures of transfer.

Some of these studies failed to produce evidence of transfer, whereas others were successful for reasons that are hotly debated (for access to this literature, see Salomon & Perkins, 1988). The failures of replication were interpreted by Papert as a failure by the researchers to realize that the "effects of LOGO" were not intended to be the result of programming per se. Rather, these effects should be seen in something akin to a cultural constructivist account, as emerging from the entire reconfiguration of educational interactions, a reconfiguration that constitutes a culture in which mediation of activity through LOGO (and not just programming per se) generates widely applicable "tools of thought" (Burns & Coon, 1990; Papert, 1987; Weir, 1987). Palumbo (1990), in an important review of the relationship between programming and problem solving, makes similar criticisms of research on other languages. Nevertheless, researchers using treatment conditions that fail to accord with Papert's expanded characterizations of the crucial processes involved continue to report "failure of transfer" of programming and other skills from the LOGO microworld to other domains (Swan, 1991).

Control Technology: Reaching Out From the Microworld

One approach that offers promise in overcoming this failure-to-transfer problem is the development of programming environments in which the student must control the technology's interaction with the real world. A study by Resnick and Ocko (1990), for example, investigates the coupling of the LOGO programming language with "technical LEGO" construction kits:

> In using LEGO/LOGO, children start by building machines out of LEGO pieces, using not only the traditional LEGO building blocks, but newer pieces like gears, motors, and sensors. Then they connect their machines to a computer and write computer programs (using a modified version of the programming language LOGO) to control the machines. For example, a child might build a LEGO merry-go-round, then write a LOGO program that makes the

merry-go-round turn three revolutions whenever a particular touch sensor is pressed. (p. 121)

Although Resnick and Ocko ground their findings in a growing appreciation of the design process, it seems important that the physicality of the environment enables constructive and authentic conversations to take place. In some way, the setting up of the problems of interaction between the designed device and the real world is more meaningful than the process of designing entirely based within the graphical world of the LOGO screen.

Computing Across the Curriculum

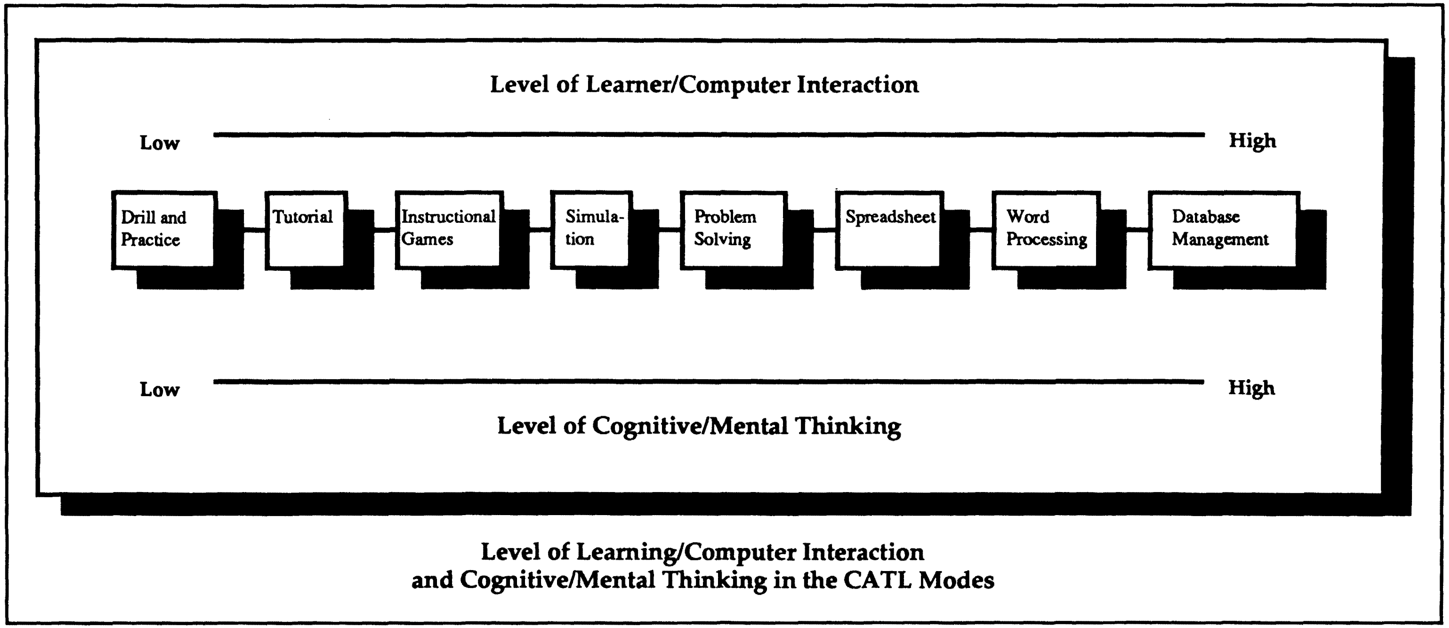
The 1991 (second) edition of a text oriented to teachers and teacher educators, *Classroom Applications of Microcomputers* (Bullough & Beatty, 1991), opens with a chapter concerned with the description of computer systems analogous to NAEP's set of knowledge skills. Only when this ground is covered do the authors turn, in Chapter 4, to a consideration of computers in the curriculum.

As Bullough and Beatty point out in their introduction, many more educators have embraced the idea of integrating computers into the existing curriculum since the previous (1987) edition of their text. They also point out that teaching about the computer has decreased somewhat except in computer science and some mathematics classes. The trend is toward the use of technology to enhance teaching in traditional subject areas. A significant component of the argument in favor of computing across the curriculum is that it does indeed enhance the character of traditional teachers; indeed, the computer may be a catalyst to promote positive changes in the teaching of such subjects. We find it significant and disappointing that, nevertheless, Bullough and Beatty feel the need to open with a view of computer literacy for teachers as "naming of parts," in contrast, for example, to Hunter (1984), who begins an assessment of computer literacy as taught throughout the K–8 curriculum in terms of the objectives of the entire curriculum.

Examining the computer literacy issue from a comparative perspective, Makrakis (1988) proposed a schema of the relation between interaction and cognition that provides a useful index of the various "modes" of computer-assisted teaching and learning in different parts of the curriculum. When we turn to an examination of selected curriculum/subject areas (for the English and mathematics areas), we present some examples of Makrakis's scheme of computer use (Figure 1). This is a device to achieve some economy on our part, and we wish to stress that examples of each mode of use can be found in all subject areas.

Perhaps this is a convenient point to mention that teacher-oriented pub-

FIGURE 1
Makrakis's Model of Computer Use in Schools



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lications, from interest groups, professional societies, and software developers, are all extremely important sources for tracing activity in the domain of computer use in the curriculum, and often contain information not available through conventional research sources. For example, Taylor is currently directing a project to develop preservice materials for computer use in art, science, music, social studies, the language arts, and mathematics (Taylor, 1991).

Complementing his previous formulation of the computer as tool, tutor, or tutee, Taylor indicates that (in each of these roles) three different specific functions of the computer need to be considered: *state resurrection, time compression*, and *graphical representation*.

By state resurrection Taylor means the ability of the computer to resurrect a particular set of prior conditions in the current computing situation. He points out the security that this ability provides to the user (e.g., to return to an earlier draft of a word-processed document), and the greater propensity to take risks and, therefore, to take an experimental approach to learning.

Time compression is the ability to compress into a short time activities that in everyday life would take much longer. Whether the activities are real, simulated analogues of the real world or fanciful, the compression factor again enables an experimental approach to learning.

Taylor also highlights the computer's ability to perform graphic representations, to represent and manipulate pictures easily. "Much of art and science has always been accessible to those who could visually represent what they were trying to understand" (p. 3). Of course, the state resurrection capability of the computer allows users to rehearse their attempts at visualization, just as the word processor allows rehearsals of text.

Modes of Computer Use

A wide variety of strategies for using computers as a tool of instruction have been developed over the past three decades. We will review these strategies, beginning with the most controlling and proceeding to those that afford treatment as "tools to think with."

Drill and Practice

When digital computers began to spread within scientific and engineering fields in the 1950s, they were initially seen as a way to implement drill-and-practice exercises whose utility derived from a behaviorist, association, and neural view of learning. This approach was viewed as especially appropriate to basic skills in literacy and mathematics education.

As computers became more sophisticated, drill-and-practice programs began to be described in terms of computer-assisted instruction (CAI)—a terminology expressing a view of teaching and learning grounded in the training and achievement of preset objectives. Many applications of, and research studies on, the use of computers in educational settings continue to be couched in this framework.

Even a good deal of the work on intelligent computer-assisted instruction (ICAI) is cast in these same terms. Although we do not object to drill-and-practice exercises per se, all too often drill-and-practice methods are used in the absence of the higher order concepts and activities for which the particular skills targeted in drill-and-practice are presumably components. In their most pernicious form, such methods are justified in terms of presumed differences in learning styles or abilities, such as Jensen's (1973) distinction between "Level 1" (rote learning) and "Level 2" (higher order learning") abilities.

As discussed in Cole and Griffin (1987) and Laboratory of Comparative Human Cognition (1989), this veiled ideology reveals itself in cases where wealthy and poor schools have equal numbers of computers but poor children spend their time on drill-and-practice exercises while better-off students spend their time in more meaningful activities (Center for the Social Organization of Schools [CSOS], 1984). This patterning makes existing reports of the effectiveness of computer-based drill-and-practice (and CAI) somewhat difficult to interpret.

Henry M. Levin (1986), for example, concluded that although CAI might improve the relative cost effectiveness of educational efforts,

> evidence at the present time suggests, however, that educators should not assume blindly that CAI is a more cost-effective intervention than other alternatives. Clearly, the overall choice must depend on a school's instructional goals, available resources for reaching those goals, proficiency of using computers, and many other factors. (p. 173)

In fact, the subject of the Levin review was a specific intervention based on the Computer Curriculum Corporation's (CCC) drill-and-practice curriculum. The CCC curriculum itself was an outcome of The Stanford Project, begun in 1964 and one of the first large-scale attempts at developing computer-assisted support for learning in the K–12 age range. The reading support components were directed by Richard Atkinson; Patrick Suppes directed the mathematics components.

The CCC implementation and development of the Atkinson-Suppes material (further reviewed in Bork, 1985) is the software used by the largest number of students participating in CAI at the public school level. According to Suppes (1988), in the mid-1980s there were more than 400,000 students, most of them "culturally disadvantaged" or handicapped, using CCC materials on a daily basis.

Suppes points out that "the main effort at CCC has been in the development of drill-and-practice courses that supplement instruction in the basic skills, especially in reading and mathematics" (p. 108). His description is important, because there has been a tendency to see such programs as a substitute for instruction by the teacher, not a supplement.

Reacting to such overzealous interpretations, Balajthy (1989) introduces a survey of computer use in the reading curriculum with an admonishment: "Computer-based education's cart has been assigned a place in front of reading/language arts education's horse" (p. vii). This admonishment, unfortunately, also is true of much computer use in mathematics education. This situation arises, at least in part, because of the facility with which computing supports drill-and-practice approaches to teaching and learning and the view of the market that such approaches, especially in literacy and numeracy, constitute a profitable area of development. Balajthy concludes:

> 1. The lower the grade level or ability of the students the more effective Computer-based Instruction (CBI) is.
> 2. CBI is consistently more effective than traditional instruction, but the amount of improvement is low to moderate and cost-effectiveness is uncertain.
> 3. Structured CBI, with emphasis on direct instruction, is more effective in producing achievement gains than unstructured CBI.
> 4. CBI results in considerable savings of learning time.
> 5. CBI results in favorable attitudes towards computers. (Balajthy, 1989, p. 77)

As Balajthy points out, research into the impact of computer-based learning on reading has been carried out since the 1960s (pp. 69–81). He isolates a number of questions: Is computer-based instruction effective? Is it more effective than other methods? What is the best use of computer-based instructional technology? Is computer-based instructional technology "just another tool"? His answer is that computer-based instruction is indeed effective—often more effective than other methods—but one must bear in mind several limiting factors.

Foremost among these limitations is the particular nature of the programmed instruction model underlying much computer-based learning (which leads to a focus on the microskills of reading inappropriate to contemporary, holistic approaches), followed by concerns that the computer is often not well enough used by teachers ("exemplary" computer-mediated teaching is rare), that too much research focuses on older rather than younger readers, and that several experimental effects have not been sufficiently allowed for.

A very important dimension of the CAI characterization of the curriculum as developed at Stanford is that of "strands," where a strand represents one content area. So, for example, in the division strand, the decimals strand, and the equations strand included in the CCC mathematics curriculum, the student progresses through a string of related items, from easier to more difficult repertoires of questions. Performance records are checked against preset criteria, and the program determines whether more practice is required. The reading curriculum in the Stanford project was initially sequenced in six strands: reading readiness, letter recognition, sight words, phonics, spelling patterns, and word meaning and sentence completion (Balajthy, 1989, p. 79).

Suppes and other advocates of traditional CAI see great virtue in the potential of linking such stranding and criterion-referenced performance monitoring to district and school grade levels and in the ability of the computer to maintain detailed strand-by-strand ratings. The achievements possible in this tradition are exemplified in the report of Suppes and his colleagues' work in applying CAI to postsecondary education at Stanford (Suppes, 1981).

Integrated Learning Systems

One of the most critical characteristics of the deployment of information technologies into education has been its commercial dynamic; that is, the manufacturers of computers, the publishers of software, and the middlemen, resellers, dealers, and system integrators have had the most to gain by understanding U.S. school systems as a marketplace. Not to appreciate the significance of the economic motive in the sale and distribution of hardware, software, collateral print materials, computer courses, and the services of the cohort of experts who provide the training and guidance for the use of these technologies is to miss the central driving force behind the technology revolution in education.

Thus, it has not been the university- or school-based educators, researchers, developers, or administrators who have spearheaded the deployment of technological adjuncts to learning, so much as those who stand to profit by the sale of these electronic systems. Among the corporations who have been aggressive advocates for the deployment of these technologies in the schools are those who create "integrated learning systems" (ILS). These corporations (Jostens Learning Corporation, itself the combining of Prescription Learning and Educational Systems Corporation, is the largest; CCC, WICAT Education, Wasatch Education Systems, Ideal Learning Systems, Computer Systems Research, Innovative Technologies in Education, and the new Century Education Corporation are some of the vendors in the ILS business) are sometimes called value-added vendors or resellers (i.e., VARs).

These corporations provide the integration of hardware, software, and curriculum for instruction. Their heritage is grounded in programmed learning and drill-and-practice, the PLATO project, and the work of Patrick Suppes at Stanford (see above). The "product" in the sale of an ILS usually consists of 20 to 30 networked computer stations, one for each student. In addition, a file server contains a vast array of instructional material, most of it not unlike the workbooks one finds in nearly every school subject and grade level. These computer labs have sometimes been compared unfavorably with the language labs that once occupied a prominent position in foreign language instruction.

The ostensible advantage of these systems is that they can give immediate performance feedback to the teacher or the student. The systems, with considerable variation depending on the vendor, all provide comprehensive basic skills training in a computer-managed program (Kelman, 1989).

These programs are accountability driven, providing continuous performance feedback (e.g., how many questions answered correctly, how many wrong, how many completed). Thus, even though students may be working on a variety of topics, skills, or tasks, the system can give the instructor a moment-by-moment analysis of what work has been done at each student station. These ILS programs account for a large portion of computer and software sales in the nation's schools, and many of them use federal and state funding sources (Chapter I, Chapter II, etc.) that supplement the standard annual operating budgets of a particular school district.

Two issues arise: the intent to tap into available funding resources that are aimed at disadvantaged, at-risk school populations who perform well below preestablished norms and the implications of differential performance expectations based on socioeconomic status and ethnic classifications. Stated simply, federally funded underperforming minority populations are the target of ILS vendors.

Computer-managed instructional systems—ILS programs—have come under criticism for their pedestrian use of repetitive multiple-choice questions and problems, underuse of the creative power of computers, and targeting of inner-city, at-risk student populations with workbook-like practice problems (while more affluent, suburban communities use computers for tutorial and simulation activities as well as for more creative applications of spreadsheets, databases, and word-processing capabilities). It is for the schools' disadvantaged populations that state and federal sources provide supplementary funding.

In a lengthy review of ILS, Kelman (1989) criticizes the targeting of at-risk students with "drill-and-kill" software, which is the standard fare of ILS systems. He identifies the heritage of ILS systems dating back to the 1960s and early 1970s, the era of CAI supported by mainframes, terminals, behavioral objectives, repetitive isolated lessons, and single-correct-answer exercises.

While most ILS vendors claim that student performance and productivity increase—scores improve—Kelman finds such research wanting on several dimensions. He criticizes ILS on the philosophical and pedagogical grounds that these systems are implicitly intended to replace some of the teaching function; they control the student's behavior, not the other way around, and they are bureaucratically convenient, "teacher proof," and teacher free.

To highlight the perceived limitations of ILS-managed instruction, Kelman lists a number of instructional areas that could be improved by computer-assisted learning but are not supported by available ILS programs: higher order thinking skills, creative expression, personal and professional productivity, cooperative learning, multiple-modality learning, and individual empowerment. Although computers can support such programs within a local area network arrangement characteristic of ILS laboratories, so far the vendors have chosen not to target these meta-cognitive domains, presumably because there is no market for them among the present customer base of administrators of inner-city and large school districts.

Tutoring

Some recent developments provide the opportunity to embed a more holistic view of learning into the CAI process and to go beyond even the most sophisticated drill-and-practice to more sophisticated pedagogical practices (Mandl & Lesgold, 1988; Psotka, Massey, & Mutter, 1988).

Intelligent tutoring systems are made up of four components: an expert knowledge component, a learning modeling component, a tutorial planning component, and a communication component. Suppes (1990), reviewing the Mandl and Lesgold and Psotka et al. books, points out that although each of the four components is thoroughly covered, there is little systematic data about the achievements of the intelligent tutoring systems approach; the references given are almost all "soft" and "qualitative" in character, in contrast to the more quantitative research characteristic of traditional CAI and drill-and-practice studies.

By contrast, Hammill (1989), in his discussion of as-yet-unmet issues in the design of intelligent tutoring systems, calls for more soft or qualitative research. He comments:

> Insights into social aspects of ITS's are also beginning to appear in the literature. For example, Schofield and her colleagues have used qualitative recording and analysis procedures to document effects on students, teachers, and even school administrators of the introduction of Anderson's Geometry Tutor into high school classrooms. Students using the tutor individually in geometry classes evidenced more effort and involvement related to geometry tasks and more competition with their peers in the classroom than did students in traditional

geometry classes. Teachers using Tutor in their classes devoted more attention to slower students; assumed more of a collaborative role with individual students using the tutor and less of an authoritative expert classroom teacher role; and changed their grading practices in response to the relatively individualized pace fostered by the tutor. And an administrator found it difficult to evaluate teachers who used the Tutor because of the very different manner in which such classes were run and the different skills required of the teachers. (p. 179)

Hammill's concerns about as-yet-unmet objectives of intelligent CAI indicate an increasing awareness of the complexity of teacher-student interactions. Hammill calls for further work on how nonformal domains of knowledge and skill might be represented in intelligent tutors, exploitation of a greater variety of instructional strategies, and greater awareness of the means of interaction between the machine and the user.

This work is nicely complemented by Gott (1989), who provides a review of intelligent tutoring systems that focus on apprenticeship relations between "tutor" and student.

Instructional Gaming

As an example of the "instructional gaming" approach or "mode of interaction," to use Makrakis's terminology, we discuss a program that is designed to increase understanding of the concept of the "number line" and that also effectively demonstrates how "gaming" approaches can be used in the teaching of well-defined concepts or microskills.

"Sharks" is a family of educational games developed by James Levin and his colleagues (see Levin & Souviney, 1983, for a general description of Levin's group's approach to constructing educational games). The metaphor undergirding various versions of the game is that of shark hunters attempting to harpoon sharks.

Different versions of the game have the shark visible or invisible at the time the estimation is made, differ the size of the shark (and therefore the ease of "hitting" it), and have the shark as stationary or moving. In addition, the games have an authoring potential; children or teachers can vary the complexity of the scale (e.g., by selecting endpoints that vary from 0 to 10, -27 to 54, or even .001 to .01).

Levin and his colleagues' design of the shark games was motivated by evidence that Japanese children who were highly practiced in the use of the abacus displayed high levels of arithmetic skill, even in its absence, and contrasting evidence that children who experienced difficulty in learning long division also had a poor knowledge of the number line, such that they had difficulty rapidly estimating "remainders." Thus, the set of games was designed to encourage learning by requiring the child to make rapid and accurate estimations of the shark's position. This was seen as a means of providing children with practice in executing operations known to be important in a valued educational context. Unfortunately, in this case, as in many cases of game-embedded computer-based activities, there is as yet no real formal evaluation of its effectiveness.

Problem-Solving Tools

Judah Schwartz's Geometric Supposer is a good representative of problem-solving-tool approaches to mathematics education. Sunburst Corporation's catalog now offers a series of Geometric Supposer programs designed to support a change in the teaching/learning process in which teachers become facilitators of geometric inquiry and students become active learners of geometry.

In the Geometric Supposer series students begin with a triangle, quadrilateral, or circle and then use menu options to attempt various constructions. Students' conjectures of appropriate constructions are based on numerical and visual data they collect, and the program provides them with tools to carry out measuring operations. Ultimately, a yearlong geometry syllabus, covering a range of concepts and including textbooks as well as the program, is built as a context for the use of the computer-focused activities.

Viewing the essence of mathematical activity as the making and exploring of mathematical conjectures rather than the ability to manipulate the operations associated with mathematics made by other people, Schwartz (1989) places the Geometric Supposer into a genre of software that he describes as "intellectual mirrors," a genre

> in which the users, be they students or teachers, can explore an intellectual domain. In these cases [i.e. the Geometric Supposers] the domain in question is Euclidean plane geometry. Because the software environment reduces the difficulties associated with the exploration of the domain and indeed provides rich tools for such exploration, those who have access to such an environment can, with the appropriate stimulation, use that access to explore the domain. I say appropriate stimulation because I believe that, for most of us, problem posing and problem solution are in large measure social activities. We need the stimulation of our peers, our students, and our teachers. (p. 58)

Other aspects that make the Geometric Supposer an intellectual mirror are that "it has no built-in pedagogic agenda" (p. 60) and that it provides a rich set of primitive operations in plane geometry—not so rich that they contain and embed answers to preset problems but rich enough that combining them in various ways allows for interesting insights about geometry.

Although the ability of the supposer to capture a construction and generalize it is important to us, and we can see how it "provides a special and supporting environment for allowing students to understand how the particularity of their efforts fits into a larger mathematical generality'' (p. 60), Schwartz's intimation of the importance of the social milieu within which the investigations are carried out strikes us as equally important and deserving of more explicit attention.

Word Processing

Much of the recent work in computer use in the language arts has concentrated on support for writing, both for its own sake and as a stimulus to literacy more generally (Daiute, 1985). There have been several initiatives to create software products that enable hesitant writers to approach writing through outlining approaches, at the precollege, college, and professional levels of process writing, or that approach writing as a collaborative process, one of computer-mediated partnership (Salomon, Perkins, & Globerson, 1991).

Perhaps the most significant computer-based initiative in the textual aspects of the language arts—if the degree to which it has been taken up by schools is taken as the criterion—is the IBM Writing to Read curriculum package. This package, in which the microcomputer is but one element among several media, was evaluated positively by the Educational Testing Service (1984). Slavin (1991) reviews several evaluations of the application of the Writing to Read program at the kindergarten and first-grade level and gives further access to the literature on this approach.

Computer Modeling and Simulation

In 1989 Robert Tinker and Seymour Papert made a number of recommendations about how computers might be used in science education, including that they should be used in science classrooms as tools for communication, for interfacing, for theory building, for creativity, for database access, and for programming. Tinker and Papert (1989) also recommend the use of computers as tools for programming in the science classroom. In their view,

> programming languages continue to be important because they give the student the greatest control of computers, putting that resource at the student's disposal in the service of student-originated activities. It is important to note that programming languages are *just below the surface* in powerful applications like Hypercard, in many word processors, and most advanced databases. As a result programming concepts are *increasingly* important. (Tinker & Papert, 1989, p. 6) [italics added]

Abruscato (1986), in a primer for computer-using science educators, also sees an extensive area of computer literacy as a valid component of the science curriculum, and Ellis (1991) reports on the ENLIST Micros project, which defined, through extensive consultation with computer-using science teachers, a set of 22 competencies needed by the teacher to make effective use of the computer in the science classroom (see Table 1).

We see here a desire to employ each of Taylor's characteristics of time compression, state resurrection, and graphic representation and visualization.

Time compression in science education. Baird (1991) summarizes the current state of computer use in science education in the context of an analysis of preservice preparation for science teachers. He notes that the extent to which science teachers are using computers in their classrooms is disappointing—computers are used by very few science teachers, most of whom feel underprepared for their use.

> Second, microcomputers and similar interactive devices offer unique opportunities for promoting multiple perspectives on science learning. Research findings point to enhanced learning outcomes and greater efficiency in classrooms where computers are used appropriately. Third, new teachers are most likely to use tools and techniques that they have been shown and used themselves. Such uses should be frequent, well-integrated into the curriculum, and involve field-based classroom settings. Finally, the rapid rate of change in educational software and hardware will require new approaches to preservice teacher education. Apprenticeships with master teachers who use computers effectively can develop confidence in newly-certified teachers and promote continuing growth. (Baird, 1991, p. 5)

Baird also reports that teachers at all levels employed roughly similar patterns, except teachers in Grades 7–12 made heavier use of the computer as a laboratory tool for simulations than those in Grades K–6. A particular instance of computer facilitation of complex problem spaces is that of the microcomputer-based laboratory, or MBL. Unfortunately, to find worthwhile instances of research in this domain would require us to go beyond our focus on K–12 education to higher education.

One stage in the transition from "drill instructor" to "object to think with" is the use of the computer to provide a framework of designed explanation, one in which a "dry lab" or simulation or "structured workbench" is run alongside the real world.

Such uses of computers have been available for a number of years; however, only recently, as scientists themselves, as part of their own practice, have adopted simulation as a research tool, have science teachers really awarded this approach to computer use much legitimacy.

State resurrection in art education. Art education has seen fundamental changes in recent years, and the role of the computer in the mediation of the new art education points to specially significant issues. State resurrection seems to be the key process in enabling computer use in art, with the availability of extremely powerful graphics programming facilities on even small microcomputers providing students opportunities to attempt,

TABLE 1

Essential Competencies and Factors

Awareness of Computers

Upon completion of *ENLIST Micros* the participant will be able to:

- Demonstrate an awareness of the major types of applications of the computer--such as information storage and retrieval, simulation and modeling, process control and decision making, computation, and data processing.
- Communicate effectively about computers by understanding and using appropriate terminology.
- Recognize that one aspect of problem solving involves a series of logical steps, and that programming is translating those steps into instructions for the computer.
- Understand thoroughly that a computer only does what the program instructs it to do.
- Demonstrate an awareness of computer usage and assistance in fields such as:

health	business and industry
science	transportation
engineering	communications
education	military

- Respond appropriately to common error messages when using software.
- Load and run a variety of computer software packages.

Applications of Microcomputers in Science Teaching

Upon completion of *ENLIST Micros* the participant will be able to:

- Describe the ways the computer can be used to learn about computers, to learn through computers, and to learn with computers.
- Describe appropriate uses for computers in teaching science, such as:
  - —computer-assisted instruction (simulation, tutorial, drill and practice)
  - —computer-managed instruction
  - —microcomputer-based laboratory
  - —problem solving
  - —word processing
  - —equipment management
  - —record keeping
- Apply and evaluate the general capabilities of the computer as a tool for instruction.
- Use the computer to individualize instruction and increase student learning.
- Demonstrate appropriate uses of computer technology for basic skills instruction.

(Continued)

TABLE 1 *(Continued)*

Implementation of Microcomputers in Science Teaching

.Upon completion of *ENLIST Micros* the participant will be able to:

- Demonstrate ways to integrate the use of computer-related materials with non-computer materials, including textbooks.
- Plan appropriate scheduling of student computer activities.
- Respond appropriately to changes in curriculum and teaching methodology caused by new technological developments.
- Plan for effective pre- and post-computer interaction activities for students (for example, debriefing after a science simulation).

Identification, Evaluation, and Adoption of Software

Upon completion of *ENLIST Micros* the participant will be able to:

- Locate commercial and public domain software for a spécific topic and application.
- Locate and use at least one evaluative process to appraise and determine the instructional worth of a variety of computer software.

Resources for Educational Computing in the Sciences

Upon completion of *ENLIST Micros* the participant will be able to:

- Identify, evaluate, and use a variety of sources of current information regarding computer uses in education.

Attitudes About Using Computers in Science Education

Upon completion of *ENLIST Micros* the participant will be able to:

- Voluntarily choose to use the computer for educational purpose.
- Display satisfaction and confidence in computer usage.
- Value the benefits of computerization in education and society for contributions such as:
  - —efficient and effective information processing,
  - —automation of routine tasks,
  - —increasing communication and availability of information,
  - —improving student attitude and productivity, and
  - —improving instructional opportunities.

From "The BSCS Perspective on Preparing Science Teachers in Educational Computing," by James D. Ellis, 1991, *SIGCUE Outlook, 21*(1), pp. 26–27. Reprinted by permission.

rehearse, and revise design processes in the search for solutions of graphic problems.

However, for the most part, art teachers have not yet realized the full potential of computers in art education contexts. Where the capabilities of computers to mediate art processes are recognized, the computer is often limited to art making. Although this computer-mediated art making may reach very high levels of practice and sophistication (e.g., three-dimensional computer animation), the more traditional roles of computer as information processor are not fully developed.

This situation obtains in a context where the Getty Trust is recording on videodisc all the major art collections of the world, collections that have themselves been indexed in computer databases since the 1960s, and in a climate where art education has broadened to a more organic inclusion of aesthetics, criticism, and history—with consequent requirements for a range of responses, including, especially, textual responses.

There have been two limitations, perhaps, on the development of a more complete approach to computer use in art education: cost and teacher training. Although costs are not yet (or ever in education) insignificant, they have sufficiently decreased in recent years to allow teachers the opportunity to take initiatives in computer-mediated art education if they wish to do so.

The limiting factor, therefore, is teacher training. This point is taken up by Hubbard (1991), who points to both the need for greater involvement in computing in teacher education and the potential leverage for instruction generally if art teachers are able to develop the potential of hypermedia and computer graphics in school contexts.

Hypermedia

An interesting dimension of the introduction of Apple's HyperCard was the difficulty that many expert computer users had in placing the new product in any existing category of computer software or pattern of computer/student interaction. Not only was HyperCard "content free" in the sense that word processors, databases, spreadsheets, and graphics programs are not limited to a particular domain, it also appeared to be "context free" and not mappable to any domain. Even its originators were unclear as to its purpose:

> We didn't know what we were making, but we knew it was going to be great. (C. Espinosa, HyperCard product manager, cited in Jones & Myers, 1988, p. vii)
>
> Even the program's creator, Bill Atkinson, was hard put to place the product in a niche large enough to house all its implications. (Daniels & Mara, 1988, p. 11)

HyperCard provides a mixture of text and graphics, text storage and retrieval, an object-oriented programming language (HyperTalk) and point-and-shoot programming, a flat-file database with the ability to input relational information, and a graphics package with sound facilities. The manufacturer's rhetoric states that "what makes Hypercard great is what makes personal computers great. They both put the power of information into the hands of ordinary people, and they both make that power usable" (Jones & Myers, 1988, p. viii). Daniels and Mara (1988) point out that system generalization of the kind evinced by HyperCard is "a two-sided coin": "If Hypercard is too general to fit all its functions into any existing category, it is also too unspecialized . . . to fully satisfy all of any given category's criteria" (p. 11).

Leaving aside the problematic issue of the affordability of the Macintosh computer by "ordinary" people, the important question to ask of HyperCard in education is not what it is, but what do people make of it? In a sense, HyperCard re-creates the flexibility of the underlying hardware substrate, and, to use Papert's phrase from *Mindstorms* (1980, p. viii), is "protean."

Padilla comments on its membership in a particular class of software programs little understood at the time of HyperCard's launching outside a limited development and research community (because powerful microcomputers are necessary):

> Hypercard is one implementation of the concept of hypertext, [a means] to break the linearity of the traditional printed text . . . one should be able to explore ideas in a multidimensional space in which related ideas are linked. The learner can then jump from one to another in a free-flowing and self-directed manner. (Padilla, 1990, p. 211)

Given such sophistication, Padilla comments: "Despite all of these complex capabilities Hypercard and Hypertalk should be viewed simply as a potential tool for productivity enhancement in regular and bilingual classrooms" (p. 212). He then proceeds to discuss some of the ways in which teachers can construct HyperCard stacks in bilingual contexts (e.g., the ability to drive interactive video through interfaces written in alternative languages). Some of the more successful uses of HyperCard in the classroom have, in fact, been in terms of students designing individual cards that are then merged together to form the group's stack. In the Apple Global Education Network (Scott & Woodbridge, 1991), several schools produced "self-portraits" of themselves through class and group projects, the resulting stacks being exchanged through the Applelink network. (A few schools even went so far as to construct stacks cooperatively, assembling them across the network.) Also, in projects analogous to Papert and Harel's "instruction-as-design" experiment, students have pursued projects to produce stacks to teach other students (Allen, 1990).

As with LOGO, HyperCard can fulfill the various roles of tutor, tool, and tutee. Also as with LOGO, the medium constituted by the tool only becomes an effective interactive learning environment when it is used as a medium of social interaction as well.

THE RESOURCE CONTEXT

In the early 1980s it was possible to be optimistic about the diffusion of computer use in education because hardware costs were decreasing rapidly and many interesting ideas were in the air; today, we seem to have reached at least a temporary cost plateau that is very high indeed for all but the wealthiest school districts.

Perhaps the power of the Next machine, the Sun work station, and Macintosh-level technology will eventually approach the affordability of the Apple IIe, still the basic U.S. school computer in terms of numbers purchased, but we do not presently see any quick movement in this direction. (Certainly, Apple Computer Incorporated's current attempt to return to a high-volume, not-too-high-cost manufacturing strategy is to be welcomed by educationalists.)

Rather, we see a desperate scramble, coincident with the ending of the manufacture of the Apple II, to acquire software and hardware from secondary suppliers before the supply completely dries up and a somewhat jaundiced view, based on previous bitter experiences of similar promises from other manufacturers, of the promised downward compatibility of the new range of low-cost Macintosh computers.

We observe this to be happening as software developers, presented with increasingly powerful platforms by the manufacturers, produce evermore sophisticated and memory-hungry microworld and simulation programs. The new System 7 operating system for the Macintosh, for example, requires a minimum of two megabytes of random-access memory, more than 250 times the size of the total memory available on the immediate postwar generation of computers, and this is not untypical of contemporary microcomputers.

Of course, Apple is not the only manufacturer to be engaged in supplying the U.S. school market. Since the advent of the personal computer, IBM has paid increasing attention to the potential returns from investing in the education market: There is much software available for the IBM microcomputer and its "clones." The Commodore Amiga has established a particular niche in graphics-oriented educational applications. All three of these manufacturers, and several others, supply microcomputers as components of sophisticated classroom-oriented packages: network and computer laboratory bundles, interactive video systems, and the like.

Patterns of Provision

Whatever the preparation of the teacher, of course, the controlling factor in the use of computers in education in a particular school is the organizational strategy adopted at that school, which relates in turn to density of provision. Although it would be pleasing to observe a process of rational design, whereby teachers work from curriculum specifications toward computer provision requirements, the reality is quite the reverse.

Decisions on the level of provision are often made at levels removed from the classroom: School districts or boards of education, computer advisers, access to commercial benefactors, current architectural fashions, and even local interpretations of safety regulations may have much more influence on determining the pattern of provision than any curriculum content requirement. Even so, one can discern some basic patterns of provision, ranging from one computer per classroom to a concentration of computers into a computer laboratory maintained by a specialist teacher.

At the midpoint of the decade, the Center for the Social Organization of Schools (CSOS, 1984) found that major issues in the diffusion of computer use in schools were the organization of student computer time, how to deal with time not spent on computers, and how to provide useful and adjustable access to few computers by many classes. The biases in this process have long been evident. CSOS reported:

> Our data show that in schools where use is concentrated among above-average students, the primary computer-using teacher reports a more "individual use" pattern than in schools where the "average" students get a proportionate share of the time. Use by "average" students is instead associated with students using computers in pairs. (Cole & Griffin, 1987, p. 53)

Cole and Griffin (1987) report on a considerable body of evidence that suggests that one computer per child is not the optimum number and that considerable benefits are to be derived from students working in pairs or small groups. These findings have both theoretical and practical significance. Their practical meaning is, of course, that one does not have to worry about getting one computer per child but can work with higher (and cheaper) ratios. Shavelson et al. (1984) looked at the strategies of teachers who had been judged successful by their peers in providing microcomputer-based instruction in cases where there were several computers in the classroom. They found that teachers employed one of four strategies for organizing computer use: enrichment, adjunct instruction, drill-and-practice, or orchestration.

Only orchestration, which represented the widest variety of instructional applications and linked those applications to the regular curriculum, provided "the appropriate integration of microcomputer-based learning activities with teachers' instructional goals and with the ongoing curriculum, which changes and improves on the basis of feedback that indicates whether desired outcomes are achieved" (Shavelson et al., 1984, p. vi).

The orchestrating teachers used several types of software that they integrated into the curriculum, coordinated the activities with other instructional means, and stressed both cognitive and basic goals. The orchestrating style seems to arise naturally when higher order, "intelligent" programs, either as focused lessons or as mixed games and lessons, are the medium of instruction, but not when drill-and-practice is used. This result stems, perhaps, from the orchestrating teacher's pattern of inclusion. Orchestrated classrooms depend, for their success, on a considerable degree of student autonomy and responsibility: They provide a context in which students naturally develop responsibility for their own learning. It follows that each new technology is able to "find a seat" in the orchestra without wholly disrupting the pattern of the classroom.

An Experiment in Computer Saturation: ACOT

Although most schools still employ one or two computers per classroom (on average) for standard educational topics, some schools have invested far more in computers in the belief that the full value of computerization cannot be properly judged without some "utopian" experiments that provide one computer for each child and, in some cases, one to take home as well (see Kiesler & Sproull, 1987, and International Federation of Information Processing, 1987, for discussions of similar viewpoints in higher education). One project that has evaluated computer use in such circumstances is the Apple Classroom of Tomorrow (ACOT) experiment, initiated by Martin Engel.

The ACOT project was initiated on the premise that every person would one day possess continuous access to computation. It was the marketing premise of Apple Computer, Inc., that there would be "one person, one computer." Corporate slogans promoted "the computer for the rest of us," and the Apple IIe was deemed "the most personal computer." The ACOT project sought to embody these slogans and concepts, implementing them within a school setting. Even this context was an extension of the corporate marketing slogan "changing the world through education, one person at a time."

In the spirit of the General Electric "kitchens of tomorrow" and the Oldsmobile "car of tomorrow," the ACOT project was intended to become a demonstration of what was possible in the hypothetical future when everyone had continuous computer access. In this case, computer saturation was created within a school setting. Every student and teacher had his or her own computer during the school day and another computer at home. Using off-the-shelf technology and commercially available software, selected classrooms around the United States were equipped with sufficient hardware to place one on each desk. Six schools began the project, offering classrooms at different grade levels.

In addition to the hardware, which was provided by Apple, and the software, which was donated by various education software vendors, Apple provided a sum of money to employ an additional person for each of the classrooms—a computer coordinator/technical person to assist the teacher in curriculum development and hardware/software support. Apple and the participating school signed a letter of intent, Apple agreeing to provide hardware and cash and the school agreeing to provide a willing teacher and coordinator as well as consenting to the "rules" of keeping the equipment concentrated within the one chosen classroom. The school also agreed to permit evaluators identified by Apple to visit the classroom, and Apple agreed to any assessment programs required by the school.

A number of assumptions drove the initiation of this project. First, it was assumed that the computer/student ratio was far from optimal and that until and unless there was a "critical mass" of technology accessible to all students at all times cause-effect impact studies would be vitiated. Furthermore, it was assumed that in order for students to benefit sufficiently from computer access, they would have to have a proprietary relationship with that technology, just as they have with their desks and hallway lockers. This idea was associated with the notion of locus of control (i.e., the degree to which students have control over the events of their teaching/learning situation). The basic assumption is that increased internal locus of control leads to increased performance.

The catalyst effect was still another assumption behind the ACOT project. The school reform movement advocates dramatic transformations in the instructional process as well as the curriculum. It was assumed that the teaching role would change in the ACOT classroom, along with the curriculum content. It was hoped that the ubiquitous presence of computers would refocus the instructional process toward the development of higher order thinking skills, problem solving, and thematic- and project-oriented approaches to the study of various subjects. It was also expected that if all students had constant computer access, they would attain greater independence, and thus the controlling role of the didactic teacher would also change toward facilitation and support.

It was expected that different schools would implement their ACOT model differently, and that, over time, through trial and error, many changes would be taking place. The notion behind this emphasis on experimentation was twofold: (a) Since there is no "science" of education, change can only come from trial and error, and (b) the ACOT classrooms would be "living laboratories," environments in which schools and school districts could learn how to make computers work for them and enhance student as well as teacher productivity and performance.

Since the project (and its research) was sponsored by a for-profit computer vendor, research credibility would be suspect, and because there continues to be a raging debate about the validity and value of educational testing, standardized and norm-referenced criteria would not be used to measure computer impact. Informal and anecdotal data were systematically collected, with participant teachers providing regular audiotaped narrations and various university-based educational ethnographers conducting observational studies.

Observational and descriptive studies of the project found the following characteristics, after 2 to 4 years of ACOT classroom development (Baker, Gearhart, & Herman, 1989, 1990, 1991):

1. Students became "empowered." The locus of control shifted to the student. Students assumed responsibility for their own academic work.

2. Students wrote more, faster, and better. Their vocabulary, sentence, and compositional complexity and comprehension improved more and faster than that of students who did not "word-process" as much or at all.

3. Students became spontaneous peer teachers and cooperative learners if permitted by their teachers.

4. Teachers diminished their didactic roles and moved toward the orchestration model.

5. Students took more initiative for their own learning. They became much less passive receivers.

6. Students learned the basic skills at their own rate more efficiently, freeing teachers from those instructional tasks to conduct higher and more personal levels of pedagogic interaction.

Although the initial investment from Apple was considerable, there was an assumption of amortization; that is, as with all capital investments, the costs, when spread over time, would increase cost-effectiveness. Furthermore, in the original conception of ACOT, costs would be controlled such that other school districts could generate similar models of saturated classrooms, if only for purposes of localizing the laboratory and investigatory aspects. Even the coordinator costs would be highest in the first year, diminishing in proportion to the number of additional ACOT classrooms added in out-years.

Looking at the impact of ACOT on teachers, Sandholtz, Ringstaff, and Dwyer (1990) report that initially teachers' concerns with management predominate and that "instructional innovation begins to emerge" only "when teachers have achieved a significant level of mastery over management issues" (p. 7). The teachers' initial problem when faced with a "high access to technology classroom," as they see it, is simply to survive.

Then they need to gain some mastery over the technology themselves before they can use it to their advantage in managing the classroom. In addition to the problems of coping with a new and therefore rather unstable technology, teachers also experience problems of infrastructure (suppliers could not keep up with the intense demand for new software and replacement media), of unanticipated misbehaviors (illegal software copying, disruption of classroom network systems, students resisting transition to noncomputer activities), and of radically changed classroom dynamics.

> Many teachers initially were troubled by the increase in noise level and the necessity for students to move freely around the classroom. Having become accustomed to students sitting in their seats and the teacher in front of the classroom, some teachers worried whether the students were on task and learning. . . . Since computers facilitated independent learning, some teachers felt that they were no longer teaching and suggested that classrooms had become "technology centered, not instruction centered." They wondered if they were accomplishing their main goal of "teaching students the content." (Sandholtz et al., 1990, p. 10)

Despite these problems, however, some teachers see positive virtues in the saturation provision of technology once they gain mastery of the new classroom order and of the technology it encompasses (Dwyer, Ringstaff, & Sandholtz, 1990, p. 11).

Preparation of Teachers to Use Computers

One conclusion to be drawn from the ACOT experience is the high degree to which teachers need support when integrating computer technology into K–12 classrooms with instructional change as the goal. A major problem involved in providing such support, through either preservice or in-service training, results from the complexity and range of educational applications of computing. This is confirmed in a report on an IBM-funded saturation project (Cline et al., 1986) that includes no less than 10 recommendations related to staff development in its concluding statement (pp. 136–137).

Other research confirms that even in circumstances where there is a requirement for teachers to gain some education in the use of computers in the classroom themselves, the development of competencies in this area is limited both from lack of time (the number of required hours is often quite limited) and from approach (such tuition is often focused on a narrow range of programs). The importance of adequate preparation is highlighted by Sheingold, Martin, and Endreweit (1985).

Lampert and Ball (1990) are developing an interesting computer-mediated approach to improving the ability of math teachers to develop "authentic" situations of mathematics learning that could serve as an exemplar for teacher training concerning both the use of computers in education and for teaching in general. In an effort to try to communicate the complexities of teaching and learning authentic mathematics in school, Lampert and Ball have collected a large amount of information from two classrooms in which this kind of teaching and learning occurred over an entire school year: videos of most lessons from two vantage points, students' drawings and writing for each day, the teacher's journal of reflections and plans, interviews across the year with the teacher and the students, and observations of every lesson written in some sort of outline form.

Lampert and Ball have catalogued this material and are now designing hypermedia "terrains" for exploration by prospective and practicing teachers who want to learn about this "new" kind of teaching. The materials they are producing could be thought of as "tutorials" that are intended to support the construction of ideas about how teaching and learning might be structured to engage participants in authentic mathematical activity. It is their intention to have those ideas firmly grounded in actual practice rather than based on theoretical ideas about what should happen in classrooms. The work stations for users will be organized around a file server that enables access to the information they have collected about teaching and learning in video, audio, graphic, and print form. Users will also be able to keep notebooks and create collaborative annotations of the information.

This kind of approach may do much to reduce student-teacher anxiety about computer use, which seems to be widespread. Attitudes toward, and anxiety about, the use of computers in the classroom will naturally affect a teacher's propensity to attempt such teaching. Woodrow (1991a, 1991b, 1991c) has made an extensive survey of various attitude scales; although he found them to be reliable predictors, he has not as yet discovered significant correlations of the determinants of the achievement of computer literacy by student teachers.

Access to computers and tuition by sensitive computer-using teacher educators seems to be a necessary but not sufficient condition for the achievement of teacher computer literacy. Certainly, student teachers seem ill prepared on the whole to cope with the social dimensions of computer use, to which we now turn.

SOCIAL ISSUES IN EDUCATIONAL COMPUTING

Microcomputer use in education raises questions of inequalities of access in terms of gender, ethnicity, and class, as already indicated.

Gender

In this section we look at recent representative work on strategies to redress imbalances in access as far as educational computer use is concerned. In considering adult roles in computer education, Michael W. Apple and Susan Jungk (1990) point out that there is a gendering that arises because teaching has been seen historically as "women's paid work," a tendency they illuminate through a study of a computer literacy curriculum.

Starting with the labor process, they point out that among the consequences of the rationalization and standardization of jobs are the separation of conception from execution and deskilling. Examining how these processes work through the job of teaching, they note that even though teachers have acquired slowly increasing amounts of skill and power in most school systems, they have only limited rights of choice of what is to be taught and how.

The composition of the teaching labor force is also of importance:

> Historically, teaching has been constructed as women's paid work. In most western industrialized nations, approximately two thirds of the teaching force are women, a figure that is higher the lower one goes in the educational system. Administrators are overwhelmingly male, a figure that increases significantly the higher one goes in the educational system. (Apple & Jungk, 1990, p. 232)

Assessing the effect of these pressures on the introduction of a computer literacy program in a school district, Apple and Jungk show that the "expertise" is situated in male teachers, two of whom are employed over the summer to write the curriculum package. Their perception of the abilities of the female teachers led them to deskill the curriculum, including attempts to encapsulate parts of it on tapes and worksheets. (There were significant limitations on hands-on access to the computer laboratory.) One outcome was reluctance of the female teachers with regard to the packaged units. Because of the time commitments (in Apple and Jungk's view, female teachers are already "doing two jobs"),

> when a new curriculum such as computer literacy is required, women teachers may be more dependent on using the ready-made curriculum materials than most male teachers. Intensification here does lead to an increased reliance on "outside experts." An understanding of the larger structuring of patriarchal relations, then, is essential if we are to fully comprehend both why the curriculum was produced the way it was and what its [gendered] effects actually were. (Apple & Jungk, 1990, p. 249)

At the student level, many studies show considerable differences between the computing experiences of boys and girls. Boys habitually have more access, whether to school, home, or recreational (arcade game) computers. Where computer programming is offered, more boys take the subject than girls (the girls take word-processing courses). Parents are more likely to buy computers for their sons than their daughters, and boys are more likely to attend after-school computer club meetings than girls.

Although computer programming is often presented as a model of a career that affords girls with unlimited opportunities, or one that affords good coordination with the demands of family, commercial programmers and systems analysts are predominantly male. "Although computers are not restricted to the male domain, the inequality is controlled by the activities that computers are a part of and that continue to be divided along traditional lines" (Cole & Griffin, 1987, p. 55).

Computer use involves language and interactivity. These are "traditionally female 'domains' of expertise" (Cole & Griffin, 1987, p. 56): Given appropriate transformations of teaching contexts designed to redress gender imbalance (such as those in math, science, and technology surveyed by the American Association for the Advancement of Science, 1984), it follows that computers *can* be employed in the curriculum in such a way that girls find them accessible and inviting.

However, girls are not currently well provided for:

> Boys seem to prefer game formats which include fantasy and violence. They do not require the same depth of instruction and understanding of a game prior to playing it. They like games and programs which are fast-paced. There is a profusion of such male oriented software on the market today. There is a dearth of software designed to attract girls. Girls, while they enjoy fantasy, are not as likely to become involved with it as boys. They do not like games which are violent or fast-paced. They prefer to have clear instructions and time to reflect on solutions. (Whooley, 1986, p. 15)

Whooley's study of gender differences in boys' and girls' use of computers concludes with an analysis of attitudes and outcomes of computer use in writing. She concludes that girls' "advantage in writing skills may provide an ideal inroad into the technology for girls to enter the field" (p. 121) and, more generally, that in collaborative work around the computer, boys working together will tend to be more impulsive, aggressive, and independent, whereas girls will tend to be less competitive and more cooperative. Of course, as she points out, none of these behaviors are of themselves negative or positive; rather, they need to be considered in context. Of cross-sex pairings, she concludes:

> If girls working with boys learn to be more confident in their application of trial and error strategies, a strategy which relies heavily on intuition for success, and boys learn from girls to cooperate in their problem solving, then each party to the interaction will have gained new ways to meet the challenges of troubles on or off computers. (Whooley, 1986, p. 122)

Given an appropriate environment in which the computer-based activities are taking place (one that promotes and expects growth and provides an opportunity for students to learn from their differences), "males and females can and do experience success in their own way" (p. 125).

One cannot leave a discussion of computing and gender without mentioning Turkle's recent work, especially Turkle and Papert (1990), which both generalizes some of Turkle's earlier work on hard and soft mastery, as presented in Turkle (1985), and proposes that cognitive styles of computer use are associated with gender.

Turkle and Papert (1990) suggest that the computer is

> an instrument for observing different styles of scientific thought and developing categories for analyzing them. [We] find that besides being a lens through which personal styles can be seen, it is also a privileged medium for the growth of alternative voices in dealing with the world of formal systems. (p. 346)

There are obvious links here to discussions on the cognitive consequences of learning to program. As a result of their investigations, Turkle and Papert wish to advance the notion of *ecological pluralism*, a notion that we see as a useful way of describing the range of interactional styles that computers allow, as well as the range of styles and attitudes brought to computer-based activities across the range of ethnicities.

Ethnicity

The use of computers in multicultural settings has a recent but rich history. Moll and Diaz (1987) showed that in a computer-mediated context where students were free to speak English or Spanish, facility with both languages improved. Bellman and Arias (1990) showed that it was feasible, through the use of telecommunications, to set up a cross-border project involving students from half a dozen institutions of higher education (three American, three Mexican) and in that context to pursue a common purpose and a common syllabus. DeVillar and Faltis (1991) have recently gathered some of the relevant literature together.

These efforts must contend with a number of underlying problems, stemming primarily from the consequences of minority ethnic group status, poverty, and problems of socially limited access to computers. The seriousness of these problems is reflected in the fact, mentioned earlier, that when minorities do have equitable access to computing resources, one observes "low-quality usage" in which drill-and-practice programs are used in place of enrichment activities, styles of classroom organization and management are adopted that reduce effectiveness of computer use, and telecommunications activities are pursued exclusively in English (CSOS, 1984; Mehan, Moll, & Riel, 1985; Shavelson et al., 1984).

In this connection there is the fact, not often enough acknowledged, that computer hardware carries cultural content: Computers can be adapted to work in Spanish, but they are designed in English. This Englishness, or more properly, Americanness, of computers is deeper than the keyboard layout and the screen driver, which can both be replaced to facilitate inverted exclamation marks and question marks. The menu structure, the design of icons, and the styles of problem decomposition and solution together construct the computer-human interface. So whatever communicative processes can be created within and between ethnic minorities, insofar as they are mediated by computer, they are also mediated by the Anglo culture.

In the light of these and other problems, DeVillar and Faltis (1991) advocate a "socioacademic achievement model" to facilitate learning in the multicultural setting—one that promotes a combination of social learning and independent practice. Although there are formidable barriers to the establishment of such models, the computer can be an effective facilitator:

> The use of technology poses a threat to group socioacademic success only insofar as educational policy relegates its use toward divisive rather than integrative means or ends . . . educational equity, then, is intimately and irreversibly tied to computer integrated technology. Without equity in the use of technology for instructional purposes, the existing disparities in academic achievement can and will only widen. (Devillar & Faltis, 1991, p. 130)

Cummins and Sayers (1990) indicate some strategies for the creation of genuine joint interaction in cross-cultural contexts in a discussion of Project Orillas and the critical pedagogy of Celestin Freinet. The Modern School Movement, founded by Freinet, linked sister classes around the world in "interscholastic exchanges" for 60 years. These were class-to-class partnerships between teachers working on joint curricular projects and making extensive use of educational technology. The exchanges, being between cultures, served to promote intercultural understanding:

> Through student learning networks, the MSM attempted to promote in young people a heightened awareness of all aspects of a community's life. Thus, technology-mediated learning networks encouraged students' development in many domains, including but not limited to academic achievement, by reestablishing the students' "psychic equilibrium" in an era increasingly dominated by mass media. (Cummins & Sayers, 1990, pp. 17–18)

Using computers as a medium of communication, rather than trying to program the machines to teach students or getting the students to program the machines, is a recent concept, Cummins and Sayers point out. They discuss as illustration of this point Project Orillas (from the Spanish De Orilla a Orilla, "From Shore to Shore"), one of several such projects

FIGURE 2

A. Educator Pedagogical Assumptions	
Transmission Orientation	Interactive/Experiential Orientation
Language:	
Decomposed	Whole
Learning:	
Hierarchical internalization from simple to complex	Joint interactive construction through critical inquiry within the zone of proximal development
B: Educator Social Assumptions	
Social Control Orientation	Social Transformation Orientation
Curricular topics:	
Neutralized with respect to societal power relations	Relevant to societal power relations
Student Outcomes:	
Compliant/Uncritical	Empowered/Critical

established or inspired by research taking place in San Diego in the early 1980s. Orillas brings together about 60 teachers in North and South America, in collaborative pairings.

As part of their agenda to elaborate the empowerment potential of computer-mediated learning networks for minority students, Cummins and Sayers point to an impasse of the pedagogical and social context for realizing such networks within the conservative educational agenda current in the United States. They present this in the form of a table, given here as Figure 2.

Cummins and Sayers hypothesize that when networking projects are implemented using their interactional/experiential orientation, ''they do have *the potential* to act as a catalyst for critical analyses by students of societal issues that may pose a challenge to the status quo'' (p. 25).

This potential arises because the collaborative input to the joint activity cannot be *pre*scripted to exclude joint critical inquiry on relevant social issues. Rather, it takes place against a background of a counterpotential in the form of the conservative approach to education, which combines a transmission-oriented pedagogy with a social-control-oriented curriculum. In order for computer-mediated learning networks to have the desired effect in heterogenous classrooms, a critical pedagogy combining interactive/experiential and social transformation orientations seems to be required.

EMBEDDING COMPUTER-MEDIATED ACTIVITY IN WIDER SOCIAL CONTEXTS

In this section we discuss three projects in which computer activities are socially structured to extend the learning activity beyond the confines of the single lesson/topic.

The Fifth Dimension Activity System

The Fifth Dimension is a deliberately constructed mixture of educational, play, and peer-oriented activities in which computed-based games and writing through telecommunications play a central role (Griffin & Cole, 1987; Laboratory of Comparative Human Cognition, 1982).

Its play elements are manifested in the culture of the Fifth Dimension, which is ruled over by a benevolent but somewhat unreliable and avuncular wizard. All of the adults, as well as all of the children, are hypothetically loyal citizens of this symbolic benefactor. Aside from collusion and playfulness in their joint ''subordination'' to the wizard, there is much play in the games themselves, which are a mixture of different kinds of commercially available software (including both arcade-style and drill-and-practice programs) and mixed genre history and geography games and clever mathematico-logical pretend worlds.

There is education, too, evoked not only by the content of the games but by the norms of the Fifth Dimension, which encourage mastery of the software and confront the children with various tasks set by the wizard at different levels of excellence. To obtain credit for their successes, the children routinely send written reports to the wizard, who arbitrates claims to expertise and privilege by getting the children to discuss such issues with other ''citizens.'' These writing exercises are simultaneously functional, although effortful from the child's point of view, and, by the researcher's analysis, cardinal moments promoting cognitive development.

While introducing children to the world of computers, the Fifth Dimension is providing the occasion for the development of a community of writers, promoting writing through authentic (if somewhat playful) correspondence. There is also education in the fact that the children are learning to make telecommunications an integral part of what they understand about technologies of communication in modern life.

The Jasper Project

"Anchored instruction" is The Cognition and Technology Group of Vanderbilt University's (1990) recommendation for dealing with the inert knowledge problem, identified by Whitehead in the 1920s as a product of conventional classroom instruction and explored in recent years by Scardamalia and Bereiter (in press); Brown, Collins, and Duguid (1989); and others.

> The major goal of anchored instruction is to overcome the inert knowledge problem. We attempt to do so by creating environments that permit sustained exploration by students and teachers and enable them to understand the kinds of problems and opportunities that experts in various areas encounter and the knowledge that these experts use as tools. We also attempt to help students experience the value of exploring the same setting from multiple perspectives (e.g., as scientist or historian). (Cognition and Technology Group, 1990, p. 3)

Note that the mediating object that the group is using is a set of interactive videodiscs, a technology within which the computer is embedded, yet accessible.

There are important ways in which interactive video and CD-Rom technology both embed and are embedded in computer technology that allow the manipulation (at the teacher level) and the exploration (at the student level) of macrocontexts. We should note also the important sense in which the group is attempting to use macrocontexts "to simulate the real world":

> Brown et al. (1989) emphasized the importance of looking carefully at what we know about everyday cognition and of creating apprenticeships composed of authentic tasks. They noted that authentic activities are most simply defined as the "ordinary practices of the culture" (p. 34). Our anchored instruction projects simulate apprenticeships that comprise authentic tasks. . . . A focus on everyday cognition and authentic tasks also reminds us that novices who enter into a particular apprenticeship have a reasonable chance to develop expertise, in part because apprentices have the opportunity for sustained thinking about specific problems over long periods of time. (Cognition and Technology Group, 1990, p. 6)

The Jasper Series is a project to develop and evaluate the use of videodisc adventures that focus on mathematical problem formulation and problem solving. The project also has cross-curricular ambitions in science, history, and literature. The series will eventually comprise 6 to 10 adventures, primarily designed for fifth-grade students. The initial adventure, which is expected to be a template for those that follow, poses a very complex mathematical problem.

Students have to generate the problem to be solved and then find relevant information pertaining to the problem. All the data needed to solve the problem are embedded in the story.

By contrast, Vanderbilt's "Young Sherlock" project, also based on an initial stimulus of a videodisc-based story and associated database, encourages students to find material "off-line" as well as within the package. What are the basic properties of these teaching resources activities that the Vanderbilt group wishes to describe as macrocontexts? First, the problems to be derived and solved are anchored in the videodisc resource; more important, the problems derived are felt by the students to be authentic. Second, the work is sustained and challenging. The discs present whole problems rather than trimmed-down representations of problems: To cope with such complexity, students must work consistently over a period of time. Third, there is a rich motivational context, in this case the visual and dynamic qualities of the videodisc medium coupled with the narrative presentations of strong story lines.

> Overall, our goals for anchored instruction include the establishment of semantically rich, shared environments that allow students and teachers to find and understand the kinds of problems that various concepts, principles and theories were designed to solve, and that allow them to experience the effects that new knowledge has on their perception and understanding of these environments. (Cognition and Technology Group, 1990, p. 9)

The Instructional Software Design Project

Harel and Papert (1990) provide one theoretically compelling model of the kinds of interactions that a fruitful computer-mediated environment would afford in their use of software design as a learning environment. This technique is essentially an embodiment of the common wisdom that one learns a great deal in the process of teaching.

In Harel and Papert's hands, the mechanism for implementing this common wisdom is a dual process where first the child must instruct the computer (e.g., write a program in LOGO to explain something) and then use that program to help teach another child, who also learns with LOGO as a mediating tool.

Harel and Papert (1990) present the Instructional Software Design Project (ISDP) as a paradigm of this constructionist vision. Fourth graders worked for 15 weeks, 4 hours a week, toward the goal of designing software to teach fractions to other children. This inversion had the benefit of making an area of learning that is usually passive into an active and exciting area of investigation. Papert (1990) describes "constructionism" as including

> but going beyond what Piaget would call "constructivism." The word with the V expresses the theory that knowledge is built by the learner, not supplied by the teacher. The word with the N expresses the idea that this happens especially felicitously when the learner is engaged in the construction of something external or at least shareable . . . a sand castle, a machine, a computer program, a book. This leads to a model using a cycle of internalization of what is outside, the externalization of what is inside, and so on. (p. 3)

Significant for us is the recognition of technology as a means of expression; the definition of the project to be tackled as one that is large-scale, meaningful, and whole; and the sustained effort required of the students toward the achievement of their goals. Also important is the shared construction of those goals. The children, the teacher, and the researcher jointly defined the meaning and purpose of the instructional software, and discussed software with which the students were familiar. Harel (the researcher) discussed her experiences as a programmer and those of other software designers, attempting to give the children a view of the process rather than of the finished product.

The binding of the researcher into the teaching/learning process, the sensitivity to atmosphere, and the replicability of the project are also significant: "The teacher and the researcher [Harel] collaborated and actively participated in all the children's software design and programming sessions . . . they looked at . . . programs, helped when asked, and discussed . . . designs, programming and problems" (Harel & Papert, 1990, p. 24).

We would say of this scenario that the designed inversion of role (students as designers and teachers) did indeed have considerable motivational power, but that the "expert" role of the researcher was also of great importance in relation to the novice designers. This was, in effect, a project about cognitive apprenticeship.

Papert attributes the fluency of the children's work with fractions to the fact that the knowledge is situated within "computational microworlds" and compares this with the situatedness of Jean Lave's (1987) respondents (weight watchers) in familiar territory (the kitchen). Harel and Papert recognize a consistency between the ISDP work and that of Lucy Suchman, Jean Lave, and John Seeley Brown: "Like these researchers we are strongly committed to the idea that no piece of knowledge stands or grows by itself. Its meaning and efficacy depend on its being situated in a relation to supporting structures" (Harel & Papert, 1990, p. 40).

But Harel and Papert also propose the situation of knowledge in "internalized supporting structures" and posit "mental environments as supporting and interacting with knowledge in much the same way as external, physical environments" (Harel & Papert, 1990, p. 40).

From our point of view, the interactive learning environment approach, which views either or both the internal and the external contexts of cognition as providing a range of props for knowledge building, misses the *mediational* essence of the "object of learning."

It is also significant to us that when Papert and Harel do discuss the importance of communication to learning, in largely Piagetian terms, the environmental situatedness of the communication is not addressed at that point.

NETWORKING

Following from our general approach to learning and development (LCHC, 1983), we consider the problem of using computers to promote educational objectives to have two sets of facets, each requiring development of different potentials in the use of computer technology.

The first, which we have been discussing for the majority of this paper, focuses on the organization of educational activity within the classroom. The second, to which we now turn, focuses on links between classroom-level activity and the broader context of which the classroom is a part.

In our view, computers always function as communications systems that mediate the interactions of their users. In this section, though, we wish to focus specifically on that category of educational computing research that most directly addresses the mediational aspects of computing: telecommunications.

As we have noted previously, "modern computer technology, when used as a component in a telecommunications system, offers a link between children, teachers, and the outside world in educationally powerful ways" (LCHC, 1989, p. 80).

The use of telecommunications affords opportunities for children to formulate and articulate new goals, to reflect on their own learning, and to use writing to create social contexts of joint activity. The joint activity does not come easily. Initial steps in children's use of networks are often difficult and uninspiring. Telecommunications use in education requires considerable planning and forethought to overcome the contradictions between the rhythms and goals of the interacting educational systems. Levin, Newman, and Crook have variously discussed aspects of the coordination issues arising in the use of computer networks to promote joint activity (Crook, 1987, 1991; Levin, Rogers, Waugh, & Smith, 1989; Newman, 1990; Newman, Brienne, Goldman, Jackson, & Magzamen, 1988).

A further issue is that of the timeliness of synchronous and asynchronous communication; computer-mediated communication provides organizers of joint activity at a distance with a crucial resource in that it occurs asynchronously, that is, in nonreal time (Black, Levin, Mehan, & Quinn, 1983; Scollon, 1983).

> The fact that an answer is not normally expected for 24 hours or more means that recipients of messages can work on them "off-line," looking up information they are lacking, consulting with more expert speakers of a foreign language, getting a partner or teacher's reaction to a proposed answer, and so on. This reduced time pressure not only mitigates problems of translation but can convert them into useful learning experiences. (LCHC, 1989, p. 81)

The time-shifting properties of electronic mail also introduce, by contrast, a sense of immediacy where the corresponding school is on the "other" side of the globe: Students in one school may proceed with a next step in the joint activity "overnight" in the other school's terms.

Studies of the use of telecommunications as an integral part of overall educational activity consistently find that, when properly organized, telecommunications provides rich opportunities for children to articulate new goals. It enables them to reflect on their own learning, to use writing as a tool for both communication and thought, and to create social contexts that are not merely "passive backgrounds" for learning but are arenas for goal-oriented, reflective problem solving (LCHC, 1989; Levin, Rogers, Waugh, & Smith, 1989; Levin & Souviney, 1983; Riel, 1986).

At the same time, there has been a tendency for enthusiasts of telecommunications-mediated instruction to replicate the errors of those who focused on the technology of mediation within classrooms in the vain hope that telecommunications access to other people and contexts (classroom, databases, and so on) is sufficient to make a positive difference in the quality of classroom instruction. It is not (Cole & Griffin, 1987; Riel, 1986). Rather, as was true of within-classroom computer use, telecommunications activities have proven powerful when they encourage both collaboration among students and a new role for the teachers. In order to do so, telecommunications activities must provide rich opportunities for children to communicate in detail about jointly addressed problems (Katz, McSwiney, & Stroud, 1987; Riel, 1988).

Apple Global Education

Among the most ambitious global networking projects, although by no means the largest or most extensive, is Apple Global Education (AGE), a program sponsored by the Apple Computer Corporation. The intent was to connect schools all over the world on an easy-to-use computer network of electronic mail and bulletin board without requiring participation in a specific program or curriculum.

The assumption was that by virtue of shared and common interests in other cultures, teachers and students at great distances from each other would have much to discuss and would be given the opportunity to create a global learning community in the spirit of Marshall McLuhan's "Electronic Global Village." In other words, AGE was meant to be a learning environment, not a particular curriculum, and a virtual classroom without walls, not a set of learning objectives.

AGE was intended to be a distributed network, democratic and egalitarian in spirit and self-renewing. Teachers and students, when on-line, were recognizable by name and contribution, not rank or age. Curriculum projects were developed by and for the schools themselves rather than imposed from outside.

The project enjoyed 2 years of rapid growth and saw the emergence of leader teachers from different parts of the world inspire large numbers of students to produce a rich array of writing and graphic projects, including animated HyperCard graphics with sound, daily newsletters, and political discussions generated out of and within hours of world events. The question the network's promoters and participants now face is whether they can build on this beginning and incorporate new schools effectively (Scott & Woodbridge, 1991).

Earth Lab

The work of Denis Newman and his colleagues at Bolt, Beranek and Newman (BBN) on the Earth Lab project indicates that the promotion of communication between children, between subjects, and between teachers through local area networks *within* the schools can also have considerable benefits for learning.

For the last 4 years, the Earth Lab project has been designing, implementing, and observing the effects of a local area network system intended to facilitate collaborative work in elementary school earth science (Newman, 1990). Newman and his colleagues' plan was to create a prototype local area network system and demonstrate it in a New York City public school using an earth science curriculum. The pedagogical rationale was that students should use technology the way real scientists do: to communicate and share data (i.e., to collaborate). The demonstration school is a public elementary school (Grades 3 to 6) located in central Harlem, New York City. The school population of approximately 700 students is predominantly African American, with a minority of Hispanic and other groups. The school's achievement scores are about average for New York City but lower than the national averages. With a few exceptions, the staff took a traditional approach to teaching through whole-class lessons, textbook reading, and worksheet drills. Under normal circumstances, the school would have been a likely customer for an integrated learning system. However, in this case, the school's computer teacher, who had a different vision, was able to play a leadership role and make use of the technology provided by the project.

Earth Lab supports restructuring through a decompartmentalization of instruction. In designing the environment, the BBN team assumed that students would benefit from seeing the connections between such topics as math and science and science and writing. Projects that groups of students undertake could be made more authentic and perhaps more motivating if related to real-world concerns where the disciplinary boundaries do not necessarily hold. Students could also become more motivated if their schoolwork were, to a greater extent, under their own control rather than tightly controlled by the school schedule. Classroom tasks might have to extend beyond the single lesson period since once students begin working with some autonomy, the project may involve new goals that are discovered in the process. Teacher relationships, including distribution of expertise and collaboration among the teaching staff, might change as student projects begin to cross over the compartmentalized curriculum structure. Evaluation of students might also have to move from the typical short-answer tests of individuals to assessments of the group performance on the project itself.

A yearlong formative experiment began in the fall of 1986. In the initial setup, a local area network connected the 25 Apple IIe computers in the school to a hard drive that allowed for central storage of data, text, and programs. The Bank Street Writer word-processing program was enhanced with an electronic mail system (Newman, 1990). The Bank Street Filer was another basic tool that made it possible for students to create databases that could be accessed from any computer in the school. Along with the technology, BBN introduced a yearlong earth science curriculum designed in collaboration with the teachers (Brienne & Goldman, 1989). The formative experiment took as its goal an increase in the frequency of collaborative work among students. At least for the one year in which systematic research was funded, BBN was prepared to modify the design of the technology, introduce new software, develop curriculum materials, and conduct staff development workshops as needed. After the first year, the school obtained an additional 20 Apple IIGS computers through an award from Apple Computer, Inc., and over the last few years has added several other computers (including five Macintosh computers). Several other application programs are in use on the network, including "hypermedia" systems, LOGOWriter, telecommunication programs, and Macintosh programs including desktop publishing tools.

Databases are used extensively both within and outside the earth science curriculum. During the lunch hour, students are found inventing databases of their favorite action figures. In social studies, students research almanacs and other sources to fill in databases about countries of the world and figures from African-American history. In earth science, they examine databases of dinosaur fossils and earthquakes and create databases of the weather readings and indicators of seasonal change that small groups of students collect over a period of several months.

The primary means for supporting collaborative groups is the Earth Lab's network interface, which makes it easy for individuals or groups to store and retrieve data pertaining to their projects. The work of the project, in the form of text, database, graphics, and code files, is stored in work spaces, folders or directories on the network file server. These work spaces, available to any computer on the school local area network, give groups a location for their work together. Students and teachers can be assigned to any number of work spaces. For example, work spaces are set up for pairs of students to work on writing assignments together.

Other work spaces served schoolwide clubs or other projects. Each individual also had a personal work space. In the first year of the project, the science teacher, who had the students for two periods a week, had the class form groups of three or four for the purpose of conducting investigations in the science lab. The science groups gave themselves names that were used for group work spaces on the network. Students share different data with different students or groups in the school, for instance, a science group, a noon-hour club, and the whole class. The current Earth Lab network system is designed to present the same information when students are on either Macintosh or Apple II computers.

When the project began, BBN's explicit goal was to create a classroom environment in which students used technology the way scientists did: for collaborative work. Their analysis of what actually happened led them to a broader conception of how the local area network technology can function. While direct support of collaborative work groups is still important, they have increasingly become interested in the decompartmentalization of the school that can result from this kind of use of a local area network. Teachers are better able to collaborate, students are better able to carry their work from one context to another, and the computer lab was increasingly used in a heterogeneous manner, with several projects or groups from different classes working simultaneously. This restructuring supports both individual and group work and contributes to a sense of community in the school.

EVALUATION

There has been relatively little attention paid to the evaluation issues that our emphasis (and Papert's) on culture creation and reciprocal-transformative interaction raises. Salomon (in press) has proposed an "in-principle" way to evaluate the relative significance of different aspects of curriculum activities viewed as cultural systems, but as yet practical applications of his technique are lacking. There is also considerable uncertainty about how to parse joint activity with respect to individual contributions. Crook's (1991) position is nearest to our own; he stresses the need to address "common knowledge" (Edwards & Mercer, 1987) in any assessment of the acquisition of computer knowledge.

At present, some combination of experimental-control group designs at the level of the system and detailed clinical descriptions of individual minihistories of mediating activity seem the most appropriate form of evaluation, although they raise issues of interpretation for which there are as yet no widely accepted criteria.

A large question concerning socially framed research projects is their replicability. Harel is attempting further instantiations of ISDP, focusing on whether and how teachers are able to appropriate the ideas and incorporate them into their own teaching, addressing the social character of learning in the ISDP environment, and assessing the difficulties of integrating such an environment into the traditional school curriculum. Such projects also raise many methodological issues, especially about evaluation and experimental "rigor." Harel has reported that the ISDP students learned quantitatively measurable skills in programming and in standard school domains vis-a-vis the control groups.

Of much interest in the pursuit of a better understanding of children's computer-mediated learning is the "thick description" of "the microgenetic moment." ISDP students' work was preserved in the students' design notebooks, in computer files preserving the state of each project at the end of each working day, and in direct daily observations by researcher, by teacher, and by video camera (either a mobile camera following "interesting events" or a static camera, constantly focused on a specific workstation.) Of this thick description data, Papert says, "it is the richness of observation obtained from so many different sources that yielded a coherent sense of the development of individual subjects as well as that of shared developmental trends" (p. 31).

The research strategy employed by LCHC concerning the Fifth Dimension activity system falls within the theoretical tradition that agrees, with Papert, that in order to create powerful educational environments one must grow a culture to support that newly created form of activity. The LCHC group and the Media Lab group share a methodology that treats the formation of cultures, of systems of activity with all the theoretically necessary ingredients for maximal development, both as a central tool of analysis and as a utopian goal. This method is what Soviet psychologists refer to as a "formative experiment," defined by Davydov (1989a, 1989b, 1989c) as "an experiment in genesis-modelling," and what Werner (1948) and Vygotsky (1978) referred to as a "microgenetic" experiment (except that in this case the modeling is at a sort of "mesogenetic" level, being measured, as it is, in terms of months and years as well as seconds and minutes).

There is a growing perception by educational researchers of methodological dilemmas that arise from research focusing on the use of the microcomputer in the classroom. Foremost among these is the growth of *qualitative* research. As Harold Levine (1990) points out:

> As interest in placing microcomputers in the classroom has increased, the interest by researchers/evaluators in assessing their potentially diverse effects has correspondingly grown. The assessment questions that arise are, in essence, no different from those posed for other educational innovations, technology-based or not: 1) What changes (and how permanent and illusory is any change)?, and 2) How do we make sense of the changes so as to justify, and properly conceptualize, their principled export to additional classroom environments? The answers to such questions are always difficult to provide, and investigators typically find themselves searching for new study designs and data collection strategies. (p. 461)

Levine then goes on to specify six models of qualitative data design and use: anecdotal, structured observations, case study, multisite case study, ethnography, and microethnography. Each of these has contributions to make to the qualitative evaluation of the impact of the microcomputer on the classroom; furthermore, each helps to focus on the embedding of the microcomputer in learning and teaching processes, in contrast to many quantitative experiments in which the microcomputer is evaluated as "an object of novelty." No doubt, the most effective educational research is that which contains a judicious mixture of quantitative and qualitative approaches and is embedded in formative, illuminative processes of evaluation rather than a search for "the one right answer." It is reassuring to note, however, the increasing emphasis on qualitative approaches as a counterbalance to the many experiments reported that are embedded in both the traditions of "computer-assisted instruction" and "controlled experiments."

The Cognition and Technology Group at Vanderbilt, the Epistemology and Learning Group at MIT, and LCHC, although differing in detail in their experimental approaches and informing ideologies of learning, share two commonalities: an interest in sustaining learning contexts over time and beyond the confines of their own experimentation and an interest in creating a research agenda (and therefore an educational practice) in contrast to the technicist tradition in educational computing.

Among the growing number of research centers with similar agendas is the Research Unit on Classroom Learning and Computer Use in Schools (RUCCUS) at the University of Western Ontario. RUCCUS's informing philosophy is drawn from the constructionist perspective in sociology, as framed originally by Berger and Luckman (1966). The initial work at RUCCUS is concentrating on the ethical and evaluative implications of methodologies derived from the constructionist perspective.

Their central concern is the ongoing examination of the social organization of classroom learning, and particularly the educational use of information technology as mediated by that social organization (and vice versa). The special interest that this program holds for us is, in part, the almost complete neglect of these issues in the general currency of educational computing research and the attempt to develop a

> new theoretical synthesis [which would] account for school computer use in context, both the context of the particular use which recognizes the constraints of a particular application, and the larger context of the educational enterprise. What is needed is research which not only avoids easy generalizations, but which questions in each instance whether worthwhile pedagogical purposes are being served. Research which examines computing in context will ask whose interests are served by a given application, how it might impact the social organization of schooling, and what consequences might be anticipated for the process of knowledge production in general. (Goodson & Mangan, 1991, p. 4)

CONCLUSION

We have seen that there are a number of ways to characterize basic conceptions of how computers should be integrated into strategies of curriculum implementation. In considering these various positions, it also helps to locate them in terms of changes in the sophistication of the computers finding their way into classrooms.

First, the computer may be considered to be the content of and constitution of a specialized area of the curriculum. In this view, the computer is a device to be programmed and a machine to be technically understood. This focus has been expanded over time to include some considerations of the social consequences of computing and definitions of computer literacy as the ability to make appropriate use of content-free software (word processors, databases, spreadsheets, business graphics).

Second, the computer may be thought of and employed as a substitute for the teacher. This approach has also been elaborated over time, moving from a focus on drill-and-practice programs as remediation of reinforcement of basic skills and "difficult" topics to a focus on the use of computer-assisted instruction as "enrichment" for the more gifted student and to the development of intelligent computer-assisted instruction programs that use expert-systems techniques to "learn about the learner."

Third, the computer is considered as a tool that the teacher can use in a variety of ways to achieve traditional pedagogical goals. This focus has been elaborated, too, and now includes open-ended programming environments such as LOGO, curriculum applications of content-free software (word processing in English, databases in history, spreadsheets in home economics, graphics programs in art), educational games, computer networks, and HyperCard. These uses are not mutually exclusive, and one may encounter classrooms where a combination of uses is found.

An intriguing question, of course, is "What variety of new forms of activity can we create more easily with computers (conceived of, in a wide sense, as including all sorts of different computer support for activity)?'' But this brings us around to the questions that motivated us at the beginning of this paper: How are we to think about the relation between computers and education, writ broad across the society? and Under what conditions are they productively used, and under what conditions are they merely a diversion?

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