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AUTHOR Lipson, Joseph I.; Fisher, Kathleen M.
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ABSTRACT

This paper explores new technologies, including computers and videodiscs, considering what they offer to education, how they can help contain educational costs, and how schools can begin to plan a smooth transition from today's primitive classroom environment to the electronically-equipped classroom of tomorrow. The introduction discusses general computer and videodisc technology and their merger in the development of computer-controlled videodiscs. Then, an overview of the learning process provides a context for the discussion of the computer and videodisc technology in educational settings. The interface between electronic technologies and learning is considered in a description of potential applications, including use of (1) microcomputers and word processors as tools for intellectual and creative expression and as instructional aids; (2) videodiscs as a means of extending experience through simulation and of using expandable text; and (3) both technologies as ways of providing access to resources and reference materials. Following the discussion of potential applications, capabilities, and advantages, the system limitations are considered, focusing on problems in current status and potential. Thirteen references are listed. (LMM)

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PUBLIC EDUCATION AND ELECTRONIC TECHNOLOGIES

by

Joseph I. Lipson
Group Director
WICAT Systems, Inc.

and

Kathleen M. Fisher
Assoc. Professor of Biological Sciences Education
University of California at Davis

Wisconsin Center for Education Research
The University of Wisconsin
Madison, Wisconsin

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Wisconsin Center for Education Research

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- diversity as a basic fact of human nature, through studies of learning and development
- diversity as a central challenge for educational techniques, through studies of classroom processes
- diversity as a key issue in relations between individuals and institutions, through studies of school processes
- diversity as a fundamental question in American social thought, through studies of social policy related to education

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Table of Contents

I

Introduction

<u>Catching Up</u> . .

The computer era has begun: The digital computer has become an integral part of the fabric of our society. Virtually every individual now needs some knowledge of computers. How computers work, how they are programmed, and what they can do should be part of the general education of most if not all future citizens.

In this paper we explore the new technologies, consider what they offer to education, how they can help contain educational costs, and how schools can begin to plan for a smooth transition from today's primitive classroom environment to the electronically equipped classroom of tomorrow.

Computers are widely used throughout American industry. They have been incorporated into production, marketing, sales, service, and virtually every other branch of corporate life.

When low cost microcomputers were introduced about five years ago, small businesses jumped on the opportunity to emulate their bigger competitors. Home computers are becoming commonplace and, in some form, will probably be in a majority of homes by the end of the decade. Most college students now have the opportunity to work with and learn about computers, although not all of them take advantage of this opportunity. In contrast, elementary and secondary education remain largely untouched by the computer revolution. Will the situation remain that way?

Alternatively, will computer assisted education lead to the eventual collapse of the formal public education system as we know it? This has been predicted by several authors, for example, Christopher Evans in his provocative book The Midro Millenium (1979). Or will computers serve to reinforce class lines? Will the economically advantaged parents provide their children with computer based education at home and send them to private or affluent public schools that make effective use of computers. If this happens, will the educationally disadvantaged fall further and further behind, attending hopelessly outdated schools?

Decisions made by schools in the next few years will be critical in deciding the future of public education in the U.S. There is already a tremendous gap to close, an enormous amount of catching up to do. With each year of indecision, procrastination, and inaction, the gap widens.

It is urgent that (a) economic disparities in the quality of education be addressed, (b) students become knowledgeable about computers, (c) the quality of education be greatly improved, and (d) the cost of education be contained. While all aspects of basic education need improvement, education in science and technology need special attention because of the increasing role that these disciplines are playing in society. The well-being of our nation depends upon the quality of universal education. Computers, as the ultimate information machines, can help us reach our goals.

The difficulties we are having in international competition, particularly with respect to Japan, are an indicator of weaknesses in our educational system. Since there is a long time lag between action and consequence in education, we will have to face quite a few more years of economic and social difficulty even if we act immediately. These difficulties should provide a strong motivation for moving as quickly as possible.

We believe that the schools can effectively incorporate computers into the existing system. We suspect that the computer and the videodisc technologies will prove to be the most valuable teacher's aides ever invented. We are optimistic that if there is a will to act, Americans can provide quality education for their children.

Computer Technology

The digital computer manipulates information according to logical rules and procedures. It can execute a large number of operations quickly. There are increasingly sophisticated programs (sequences of logical commands) and programming languages designed to help us capitalize on the basic act of computation in many different ways.

Initially, computers were relatively large and expensive. About five years ago, engineers and scientists learned how to produce a silicon chip that incorporates the equivalent of thousands of transistors, and the low cost microcomputer was born. Since then, the power of computers has approximately doubled every two years while the price has remained more or less constant. This is significant for schools. The ability of a computer to deliver useful instruction depends in part upon its computational power and the size of its memory bank. As the computational power and memory that a school can afford increase, more interesting and "intelligent" programs become possible. Such programs can be both economical and instructionally effective. Eventually, it will be impractical for schools not to make use of computers.

Videodisc Technology

The laser optical videodisc stores information on a plastic disc similar in size to an LP record. The information is read by a laser beam. The variations in reflected laser light are transformed into a video image and accompanying sound. Each side of the disc has 54,000 turns of a spiral defined by millions of tiny pits in the silvery surface. Each turn of the spiral contains the information for one image. Thus each side of the disc holds 54,000 individual "frames" (images, pictures). Since the laser beam "reads" the disc without touching it as a phonograph needle touches an LP, it can hold on one frame indefinitely without wearing out that portion of the disc. Further, an electronic command can, within two to five seconds, move the laser beam to any one of the 54,000 images on one side of a disc. The ability to move quickly from one part of the disc to another is essential for branched instructional programs. In effect one side of a disc provides access to a collection of 54,000 slides. The disc can also store moving pictures from film or videotape sources. One side of a disc will hold one-half hour of film when played at the normal speed of 30 images per second. Almost any degree of slow or fast motion is possible. Moving and still images can be combined in any proportion.

In summary, the videodisc can store moving pictures, still pictures, printed words, symbols--anything that can be captured by any of the media available today. These can be mixed in any proportions on a disc. A moving image can be examined in actual time, slow motion, or fast time, or it can be stopped and held motionless at any frame.

We don't often think about the relative density of information or its relative cost, but the videodisc brings this into our consciousness in a powerful way when we reflect on the fact that one side of a disc will hold about 2,500,000 words, 54,000 still pictures, or one-half hour of moving pictures. This illustrates a point we return to later: that words, printed materials, predominate in our educational practices in part because of economic considerations.

The videodisc and the computer can be combined in instructional applications. This allows the viewer to interact with the program:

respond to questions, ask questions, give instructions, and so on. The computer can respond by branching to an appropriate part of the program on the disc. Computer generated characters--words, numbers, symbols--and computer generated images--lines, line drawings, charts, arrows--can be superimposed on images from the videodisc.

If you haven't yet seen the computer controlled videodisc, perhaps this brief description will at least let you begin to appreciate the power it offers as an instructional tool. The discontinuity between real life and representations of that life can be immeasurably reduced with this medium. The computer-controlled videodisc can enrich education enormously--if we learn to use it effectively.

II.

Learning and Knowledge

The Nature of Learning

A brief overview of the learning process is presented here to provide a context for the discussion of computer and videodisc technology in education. In the attempt to be both brief and interesting, we have taken liberties with the formal academic style of discussion. We believe that what we describe is plausible in the light of current knowledge, although much may be considered speculative. When we describe what goes on in someone's mind, there is an inductive leap that the reader must tolerate: we observe patterns of behavior and infer that certain processes are taking place. Our justification for this is that all of us operate on the basis of implicit and explicit models of the world. In the following discussion, we are trying to make our model explicit so that you will be able to see the link between our model of learning and our view of the role of the computer.

Expectation and Response. Our basic assumption is that there is a biological basis for behavior. That is, organisms learn primarily through changes in the physical properties of the nervous system. The changes may be structural, as in the proliferation of dendrites; electrical, as in the conditions for passage of an electrical nerve impulse; or biochemical, as in the conditions for passage of ions across membrane. As the nervous system is modified, the flow of information through the nervous system is altered. There is a growing body of evidence to support this physiologic view of learning. For example, animal young raised in environments that are rich in positive stimuli have much richer dendrite (nerve process) development than those raised in barren or traumatic environments. Also, various chemicals have been identified in the brain that influence learned behavior.

At each instant, an animal has a set of expectations generated by the stimuli that it receives. A certain smell means to expect food. Another smell means to expect danger. The sight of water generates the expectation of relief from thirst. In the simplest model of behavior, as long as one's expectations are confirmed, all is right with the world and there is no need for additional learning to take place.

Learning, modification of expectations and responses, is caused by a challenge to one's expectations. When something happens that was not expected, the animal or human must somehow come to terms with this novel or unexpected event. Expectations are then modified--that red color means the object is hot--and behavior is modified accordingly--don't touch the stove. Higher organisms often seek out novel and challenging events and this increases the probability of encountering occasions for learning. How often do we consciously use challenge and surprise to motivate and interest our students?

Gradually, as we acquire more and more experience in a given domain (e.g., physical space, social interaction, food, games, one's own body), we build up what might be called a mental model of that domain, a "world view." Kelly (1955) and White (1959) propose that each of us constantly builds a model of the world and constantly checks that model against reality. Such a world view helps us to carry out some of the myriad operations we execute in daily life. We decide where to direct our attention. We anticipate the place to put each foot as we walk or climb stairs. We have an idea of how people will respond to a smile or a frown. However, life is always full of surprises, and no matter how much experience we have, we are never completely free of novel events that challenge us and lead to changes in our world view. These changes sometimes consist of small adjustments and at other times involve major restructuring of the model. As a youngster matures, learning involves such repeated and sometimes painful alterations in world view.

Attention and Motivation. For learning to take place, the learner must focus attention on the material to be learned. There may be some subliminal learning, but this is not believed to be of great consequence in formal education. Out of the immense sea of signals that reach the senses, especially the eyes and ears, the learner must pay attention to the relevant information which defines the lesson or task. The student must be willing to pay attention to lesson goals and materials defined by others. There are, of course, many reasons for individuals to accept the implicit contract of being a student, such as fear of consequences of noncooperation, desire to please someone, interest or ability in a subject, and curiousity and desire to explore.

The motivations of individual students vary. Students' intentions, goals, attitudes, expectations, and preferences play an important role in their approaches to learning. Teachers and schools attempt to motivate students by using various combinations of the factors above. They work continuously to focus the student's attention on the learning tasks. They challenge the student with grades, puzzles, novelty; they attract the student with rewards, promises, attractive materials; and they pressure the student with social pressure, grades, and implied and explicit threats. As the students mature, more opportunities are provided for pursuing individual goals and interests, and greater discipline is expected in the pursuit of those goals and interests. One of the most universal human desires is the desire to be competent, to have control over one's environment. The desire to achieve competence becomes a driving force for many older students. The resulting emotional (affective) connection helps the student to maintain commitment and engagement even in the face of extremely demanding curricula such as medicine, law, and engineering. Other students become discouraged or disinterested as they grow older, feeling not power from learning but frustration in school.

Emotions are intricately related to effective learning. As mentioned earlier, all of us are bombarded by more signals than we can possibly pay attention to at any given instant. Therefore, we must have some decision rules within us to determine what we will pay attention to and what we will ignore. One essential part of the decision process is tied to our emotional responses to the different signals that are competing for our attention. Many motivating factors are emotional. Vivid moving and still pictures, games and other aspects of the new technologies may appeal to the emotions and increase involvement in learning.

<u>Importance of Images</u>. Images can provide models of skilled performance to guide the efforts of the student in such areas as handwriting, sports, crafts, the rules of social interaction, medical skills, and possibly intellectual performance.

Images can provide a sort of motion picture of important processes ("runnable models" to use Alan Collins' term[1]) such as cell division, the rainfall cycle, the operation of an internal combustion engine, and so on.

Images can give the student the rich supply of examples that can help in the attainment of important concepts such as cell membrane, cell nucleus, classes of minerals, classes of machines, species, classes of human interaction (e.g., pecking order), classes of human society (e.g., tribal).

In general, the evidence suggests that observing images is not, in itself, a powerful learning device. However, in combination with other, more direct methods of instruction, the opportunity to observe images of that which is to be learned seems to greatly decrease the time for learning. We would propose that if images become sufficiently inexpensive, the integration of images into an instructional system would enhance that system in quite noticeable ways.

Consider these examples: a scientific discussion of the rainfall cycle, a description of the operation of an engine, a poem about a lake, a story about Walden Pond. With a book, the student is asked to learn about the event or thing through words without having observed it. At best, a photo or diagram might be included in the book. With a videodisc, scenes or events can be pictured so that language may be used to describe scenes and events that the child has seen and can visualize. Experience tells us that the second kind of learning is generally preferable because the rich visual experience gives more meaning to the words and because the words are being chosen to fit the images.

Formal Education

As culture develops, certain skills and knowledge become formalized and ritualized. People are often encouraged to learn certain things in abstract ways without being challenged by events or experiences. This is one of the functions of the school. School is an artificial world in which the modification of expectations and responses is not left to chance but is carefully orchestrated to produce specific, desired performance. Exactly what knowledge and skills are to be included in the curriculum is determined by various adults in the society. However, curriculum revision usually lags behind societal advances because of the complex and cumbersome nature of (a) recognizing changes, and (b) responding to them in appropriate ways.

There are, of course, many levels of events in school. There is the informal or hidden curriculum of socialization, in which students feel pressure to find and accept unique roles in the society of the classroom. There is also the formal, codified curriculum: language, mathematics, literature, science, and so on.

Declarative vs. Procedural Knowledge. Research into the nature of learning suggests that humans learn procedures (e.g., assembling a carburetor, baking a cake, performing the long division algorithm) differently from declarative knowledge (e.g., listing the major organs of the body, naming the state capitals). This distinction is often characterized as the difference between knowing how (procedural) and knowing what (declarative).

Schools are sometimes criticized for overemphasizing declarative knowledge and underemphasizing procedural skills. We conclude that there are economic reasons for this emphasis. Procedural skills often involve material resources as in a carpentry shop, an automotive shop, an art studio, or a science lab. The purchase and management of these materials is expensive. In addition, instruction with shop, studio, and lab materials requires close attention by an instructor. The learning process in these settings tends to be relatively slow and time consuming. Assessment of procedural knowledge is also more difficult than assessment of declarative knowledge. Consequently, shops, studios, and labs have generally been reserved for affluent school districts and for the later years of schooling.

In contrast, words, numbers, and mathematical symbols are comparatively inexpensive. Of course, procedural skills may involve words and symbols as well as more concrete materials. Preparing an outline, diagramming a sentence, solving a math equation, and analyzing a physics problem are procedural skills that can be presented and solved with words, symbols, and line drawings. The ability to manipulate abstract symbols is one of the most dramatic of human intellectual skills.

Education and Training. There is an important distinction to be made between education and training. Training is preparation for well defined future tasks, such as operation of a lathe, a typewriter, or a computer. Education is, in contrast, preparation for unknown future events. A good education curriculum accurately anticipates the kinds of knowledge and skill that will be important in the future. For example, American society expects that individuals should know how to read, whatever form the future takes. Curriculum debates often arise from differing visions of the future. For example, some people say that with hand calculators being so inexpensive and readily available, we should no longer spend time teaching the long division algorithm. Others envision disaster if we fail to teach that particular skill. In each case the statements regarding the curriculum are influenced to some extent by views of the nature of future society. Sometimes we make curriculum decisions without assessing present and future developments in society, and these are usually bad decisions.

It should be recognized that the distinction between education and training is not always clear-cut. There are elements of general education in the most vocational lesson and elements of training in what is thought of as general or liberal education. Much schoolwork seems to involve explicit training, multiplication tables, combined with implicit education, mathematical logic.

Language and Experience. Alan Newell (1978) said that if he had to characterize humans, he would call them The Great Recognizers. We have the ability to recognize scenes that we have seen before with a remarkable degree of accuracy. Recall of objects, events, and scenes tends to be stimulated by visual similarity. For example, seeing a river can stimulate recall of a river seen previously. Seeing a car can stimulate recall of another car.

Language provides a powerful "shorthand" of symbols with which we can file and retrieve experiences. For example, we may ask a student to recall five buildings s/he has seen or three rivers s/he has crossed. The words "building" and "river" are connected to a rich array of personal experiences and examples.

Philip Morrison once said, "Language gives us yesterday and tomorrow."[2] Language is the scaffolding of experience. Because many different experiences are drawn together by a single word, language gives us the ability to mentally span time and space. When we think of the word "apple," we can remember the apples in our childhood experiences, the apple trees we enjoyed as youngsters, and the apple pie we ate last Christmas.

As we generate more abstract concepts, the brain links different parts of our experience in more and more intricate ways. For example, we may be asked to think of all the ways that energy flow influences our society. Language is essential in achieving more complex thought processes.

In summary, experiences without words are difficult to integrate, describe, and retrieve. This may be why we remember so little of our infant life, before we had language to help organize our memories. Words give us access to our past experiences and enable us to imagine future experiences. At the same time, words without experience tend to have limited meaning.

The two reinforce each other and are defined by one another. Both experience and language are affected by expectations: we hear what we expect to hear and see what we expect to see.

III

The Interface Between Electronic Technologies and Learning

Tools for Intellectual and Creative Expression

There are many computing devices that are ideal for creative expression as described below. At the moment, however, the videodisc is not very useful as a tool for creative expression in the classroom, since it is not possible for students to compose or invent on the videodisc. Thus, the videodisc will not be included in the discussion below.

The Computer-Based Word Processor. This is a specialized tool that greatly simplifies the mechanics of writing, editing, correcting, and retyping a report or manuscript. In fact, word processors so facilitate scholarly production by minimizing the mechanical details of writing and permitting maximum attention to the flow of ideas that the authors of this paper have become addicted to them.

The following story illustrates their usefulness: About a year ago, one of us had to revise a large manuscript in just one evening. The paper had been drafted earlier, and detailed editorial comments had been obtained from three readers. There were revisions, often major ones, to be incorporated into forty pages of text. Fortunately, the paper had been prepared on a word processor so that corrections could be made instantly on a computer terminal. After the corrections were completed, the paper was printed by the computer printer. The printed document was then copied and collated by a modern office copier. The entire operation was completed in just three hours. Imagine how much longer this operation would have taken if the paper had gone through the old routine of (1) preparing an edited master copy with hand written corrections and inserts, (2) having a secretary type a new draft from the edited copy, (3) proofreading the retyped copy, (4) correcting the typing errors, and (5) copying the final copy.

Modern word processors are extremely easy to use. They take much of the agony out of writing because each draft can be produced as clean, neatly typed copy. It is as easy to make major changes, such as rearranging sentences and paragraphs, as it is to make minor corrections such as spelling errors. These assets must surely be as attractive to beginning writers as they are to scholars.

Many computers have auxiliary programs to aid in manuscript preparation. For example, there is a program called "Spell" that will review an entire document and identify all misspelled words. The author can then determine the correct spelling (which on some computers can be done with the help of an on-line dictionary) and edit the manuscript accordingly. Similar analysis programs could be imagined for the instruction of young children--such as one that picks out the subject and verb of the sentence.

In summary, with word processors students could achieve a higher level of quality in their creative and technical writing, whether a story, a laboratory report, a yearbook, a class newspaper, or whatever. With the mechanical details of writing minimized, students can pay greater attention to content, form, and style. And with the satisfaction that comes from producing clean, professional looking copy, students may be more motivated than ever before to tackle the task of composition.

Teachers can use word processors as classroom instructional devices. This is already being done in some universities. Using a large screen or projected image, teachers can work with a whole class to edit or review a document, to diagram sentences, and so on.

Microcomputers as General Purpose Tools. Microcomputers can help students produce not only text but also music, line drawings, geometric shapes, and animation. By composing computer graphics youngsters can explore the basic concepts of art such as color, balance, form, visual flow. In fact, some of the most imaginative uses of computers have been in the creative arts. For example, computers enable a single person playing a piano keyboard to sound like a string quartet, a woodwind ensemble, or an entire orchestra.

Limited computer intelligence probably incurs the least annoyance when the computer is used as a tool. For example, the word processing program used to prepare this report is not very advanced in comparison with many word processing programs now on the market. Yet it is so much better than a typewriter that we constantly marvel at and feel good about its help. Similarly, graphics terminals, programmable calculators, and digital computers that are used in research are appreciated because of their ability to amplify our intellect, just as a tractor amplifies our physical ability.

We feel there is an important distinction between the "computer as teacher" and the "computer as tool." We use tools to help us work toward some goal. If we are solving physics problems, a programmable calculator is a useful aid. If we are engaged in a social science research project with a complex statistical design, the computer is a godsend. We can sense the work saved and the intellectual potential provided. When the computer is being used as an instructional device, we don't use it to achieve our goals; rather we give it the lead and try to achieve the goals it sets out for us. In this case, its limited intelligence is apt to frustrate and annoy us because of a "pretense" of intelligence and sensibility that cannot be sustained. When the computer has sent the same message of congratulations to us for the umpteenth time for answering correctly, the limitation of the device is apparent.

Thus, we feel, as do many others, that more instruction should be created involving the computer as a tool, at least until much more intelligent instructional programs are written. This is the approach Dr. Seymour Papert (1980) has taken. He gives young children a special language (LOGO) that they can use to "teach" the computer to do interesting things of their own choosing. Of course, to use the computer as a tool we must learn its properties, just as we must learn the properties of any instrument we wish to use--a lathe, a camera, a microscope. This approach deserves serious consideration in elementary and secondary education since there is no doubt that the people who can successfully use the computer as a tool will play an increasingly important role in society in the future.

Are there instances where computers should not be used as tools? For example, will computer music lead to the elimination of conventional musical instruments? So far, this seems unlikely. What seems to happen is that new musical ideas are explored with computer technology, and these ideas are then expressed using electronic technologies, conventional instruments, or a mixture of the two according to the aesthetic preferences of the artist and the audience.

On the other hand, penmanship is likely to decline if students begin composing text on computers in the early grades. Is this a serious loss in the education of our people, or does it represent constructive evolution in what is important to know? We lean toward the latter view. Most people today do not know how to can vegetables, spin wool, or milk a cow. This lack of knowledge is not a serious deficit in a modern society where all of the commodities are available at a local store. It would be serious if we were to be cast back into a more primitive form of existence. Similarly, writing with a handheld tool is a primitive art that may have no place in the electronic society of tomorrow except as an artistic skill, as calligraphy is today. It would be foolish to eliminate penmanship from the curriculum before the transition to a fully electronic society is completed. At the same time, it seems equally foolish to attach too much significance to this skill. The continuing need for penmanship should not cause us to suppress the use of computers in composition.

Knowledge of the multiplication tables and the long division algorithm may be--probably already has been--eroded by the advent of the inexpensive, hand-held calculator. Like many others, we are less confident that this loss can be ignored. These skills may be important to the understanding of higher level math skills. We feel it is important that students should learn to use basic computation skills routinely to estimate answers to check either their own math or that performed by a computer. Students should rely on their own computational ability to answer the question "Is this answer reasonable?" when examining the answer to a practical or scientific problem. If students acquire the ability to estimate in their heads routinely while obtaining mathematically precise answers with a calculator, the use of calculators would be appropriate.

<u>Instructional Aids</u>

<u>Computers as Tutors</u>. The small modern computer is very stupid compared to a teacher. However, in terms of its ability to analyze and react to certain kinds of student work, it is tireless, infinitely patient, and nonthreatening. It is excellent for drill and practice with immediate feedback. For example, computers can generate sequences of mathematics

problems according to parameters set by the teacher or programmer. These problems can be printed and given to students as homework or worked on-line. The former arrangement is desirable if (a) class time is to be conserved, or (b) there are not enough machines to permit individual students to work at the terminal for extended periods. The computer can also evaluate the students' work, indicating which answers are correct and providing additional instruction, information, or direction where needed. Computers can also analyze patterns of success and error in order to reveal deeper misunderstandings. Appropriate assignments by the teacher and feedback by the computer can help correct such misunderstandings. Because of time limitations, computers can often give much more detailed feedback than teachers.

There are already a variety of programs available for teaching arithmetic, spelling, geography and other basic subjects. These have been designed primarily for the home computing market rather than for formal educational programs.

Addition of computers-as-tutors to the classroom environment can make teacher-student interactions more fruitful by expanding the student's base of experience and practice. Access to a computer may give students a wider range of experience in a subject than was previously possible.

John Seely Brown, Alan Collins, and G. Harris (1978) and others are working to develop sophisticated tutoring programs. Sophisticated tutors have (a) knowledge of the subject to be taught, (b) a model of the individual student's learning modality, and (c) an ability to react intelligently to a wide range of student initiatives.

Brown's "buggy" program (Brown & Burton, 1975; Brown, Burton, & Hausmann, 1976) illustrates both the potential and the difficulty of this approach. Brown and others, particularly Robert Benjamin Davis (1982), suggest that young students do not always make random errors in simple addition and subtraction. Rather students often seem to make systematic errors, as if the arithmetic programs in their brains have defects, or bugs, in them. Brown's group charted all or most of the possible errors that could be made in simple addition problems. Once this was done, the group programmed a computer to analyze students' errors and identify ones that are made systematically, the bugs associated with each student. Such an analysis could help a teacher and eventually a computer program to tutor the student to eliminate sources of systematic error.

Until recently, teachers rarely noticed children making systematic math errors. The computer was important in detecting such errors and is virtually essential for any full-scale analysis of them. If an effective diagnostic computer program is produced, it could conceivably help every student in the country at very little cost per student.

The complexity of many human thought processes suggests that it will be a very long arduous task to develop intelligent tutorial programs. More powerful, more appropriate languages, and more complex programs will be needed.

Computer Games. Many computer games and simulations have branching operations embedded in them. For example, in the game Adventure, the player often has a choice of actions such as throw a knife at the dragon, go east, climb tree, look around. A different consequence results from each choice. The essential contributions of the computer are to serve (a) as an opponent whose skill is matched to that of the learner, (b) as a game manager that keeps track of the details of the game, and (c) as a library of available games.

Each of the games is what has been called a microworld--a small arena in which a special set of rules apply. Almost any game is like this. Computer games can be more complex than board games. In general, the larger and more clever the program, the more interesting and challenging the game. There are several different programs designed to play chess with a human player; these are probably the most sophisticated examples of computer intelligence in games so far created.

Theoretically, instructional games can be devised that both teach and have the motivational properties of games. An important report on this, "What Makes Things Fun to Learn? A Study of Intrinsically Motivating Computer Games," by Thomas W. Malone (1980) should be read by anyone interested in this subject.

In our view, computer games have not yet made a significant contribution to formal instruction. It may be that the capabilities of the computer and the quality of programming have not yet reached the level needed for that contribution, or there may be other problems involved in trying to combine games and instruction. We should not give up, however. The idea of a simulated world in which learning enjoys the same level of motivation and challenge as that associated with games, at least for some people, is worth pursuing.

Computers as Instructors. As noted previously, instructional programs can be presented via computer. Such instructional packages are commonly used by the Bank of America, IBM, Digital Electronics Corporation, General Electric, and other large corporations for training new staff and for imparting new skills to existing staff. These programs typically are highly branched and permit a lot of learner control. For example, the learner may request additional examples to illustrate a particular concept, may ask for an explanation of the meaning of a word, or may choose to skip a section s/he knows fairly well. The computer frequently presents problems and questions to the learner to monitor the learning process. Depending upon the student's responses, the computer may branch to simpler, more detailed explanations or to higher level materials.

Videodiscs to Extend Experience

One goal of education is to extend both language and experience so that we have (a) words to help us capture the important aspects of experience and (b) the experiences that will help give meaning to the concepts presented. Another goal of education is to have the procedural (psychomotor and intellectual) skills to carry out our plans, our intentions. To achieve these goals learners must, like scientists, repeatedly go back and forth between language and experience--checking the accuracy of their perceptions against their verbal and symbolic constructions of those perceptions. As noted earlier Kelly (1955) and White (1959) propose that each of us constantly builds a model of the world and constantly checks that model against reality. To do this we need both language and experience, and we need to be aware that each of these systems (verbal and perceptual) has distortions, gaps, errors, and flaws. The videodisc can facilitate this process immeasurably. It gives us the opportunity to incorporate visually rich illustrations into our instructional process on a regular basis.

Until now, teachers have generally had to choose between media: That is, shall they buy a new book (words) or a new movie (images)? With the videodisc, educators are no longer forced into an either/or choice. A verbal and diagrammatic explanation of cell division, for example, can be enriched with a two or three minute time-lapse film of cells dividing. Images of actual processes will enable students to remember them much more vividly than the vague, abstract words we use to describe processes, especially when those words are unconnected to relevant experience.

Using images to provide visual experiences is probably not of great educational interest until the student is asked to describe the events, answer questions about them, predict what would happen if conditions were modified, etc. It is what we ask the student to do that transforms information into an educational experience. One way to get students to use their knowledge in an interesting and useful way is to ask them to participate in simulations that incorporate important relationships.

Simulations. One of the most promising uses of the computer-controlled videodisc is the simulation of complex systems that require a combination of knowledge and skill. For example, a computer simulation of a nuclear reactor called "Three Mile Island" has received excellent reviews. The University of Utah Physics Department is using a computer plus videodisc to provide a realistic simulation of the operation of an oscilloscope. WICAT Systems is producing videodisc programs to simulate the process of diagnosing medical conditions. Simulations are also used for training astronauts and pilots.

In general, whenever realistic images can improve instructional quality, a videodisc can provide those images. For example, in medical situations, the doctor must interpret the appearance of tissue, X-rays, a patient's expression when answering a question, and so on. In such cases textbooks or computers alone are not able to provide the images needed. The "intelligent" videodisc is a marked improvement.

Expandable Text. Images are not essential to a student who has rich experience in the domain being studied. S/he can use his/her own memory to give meaning to words and can often accept verbal instructions that are very brief and succinct. In group instruction it may be desirable to provide swift, succinct instruction for those who can use it and offer more verbal explanations and/or visual experience for those who need or want it.

The videodisc can provide such an "expandable text." Command keys permit the student to move up and down through several levels of information in both the verbal and image dimensions. For example, the student could ask for definitions of certain concepts in cell division, or for a more detailed explanation of the process. Alternatively, the student may request another view of the process of cell division, perhaps specifying animal or plant cells. Often the photographs of a biological event are difficult to interpret because the objects of interest do not stand out (e.g., vesicles near a membrane). In such cases, the student could call for computer animation with line drawings, or the superimposition of line drawings on top of color or halftone photographs to isolate and highlight structures.

If the student wanted multiple examples to form a concept, s/he could keep asking for examples and problems until the concept was firmly fixed in mind. Similarly, if the author or teacher felt that multiple examples were important, a series of them could be presented to the student and the student asked to interpret each one.

Note the awkwardness that arises when we try to distinguish between words per se and the objects, experiences, and processes that words represent. We feel that confusion between symbols and the things the symbols represent is the source of many difficulties in our teaching practices and in the minds of children. Nevertheless, for this discussion, the distinction is important, and we hope we have succeeded in making that distinction.

Access to Resources and Reference Materials

Large computers can search information files and bring to the screen any information that is stored--and almost any kind of information can be stored: verbal, aural, visual, and even three dimensional. Smaller computers can perform similar functions but with smaller files.

Economics of Intelligent Videodiscs. The two sides of an intelligent videodisc can hold 108,000 individual frames or pictures. Each frame can be held on the television screen as long as one likes. Thus one can think of the videodisc as a book with 108,000 pages. However, because of the poor resolution of the television screen, each video page cannot hold as many words as a normal printed page.

The following examples may convey the tremendous storage capacity of the videodisc. A book of 1000 pages is a very large book. Imagine a library of 100 picture books each containing 1000 pictures of some subject. How much would one expect to pay for a picture book with 1000 pages of pictures? At ten cents per page, the price per book would be $100. This means that the pictures from a single videodisc, if in book form, might cost $10,000! Yet a programmed videodisc can sell for $50.

Now let's look at the capacity of the videodisc to store words--not its strongest point because words alone fail to capitalize on the potential of the technology. Imagine that each frame of a videodisc contains just ten words. An entire videodisc could then contain over one million words. This would be equivalent to about 2,700 pages of text having 400 words per printed page. If one estimates that each page of printed text costs 5 cents, the book would be worth $135.

Actually, a videodisc frame can easily contain 50 words. A videodisc with this density of verbal information (50 rather than 10 words per frame) would be equivalent to printed material costing $675 (assuming the same algorithm as above). Since an "expensive" videodisc so far costs no more than $50, and most videodiscs cost $15 to $25, the videodisc clearly contains a tremendous amount of information at low cost. The capacity of the videodisc is shown to best advantage with combinations of words and moving and still pictures. Even as a library of words alone, the videodisc is economically competitive.

But what about the cost of the equipment? A computer-controlled videodisc player will probably cost about $2,000 in the foreseeable future. Thus, the capital cost is not negligible. Let us assume that a videodisc player could be used for ten hours a day for five years, and that it may cost $2,000 to maintain and service the computer-controlled player over that five-year period. Also assume that it will be used about 250 days of the year. This would give a total usage (10 x 250 x 5) of 12,500 hours at a total cost of $4,000, or about 30 cents per hour. If a student can read 30 pages an hour, the cost per page is about 1 cent.

Trends in information storage suggest that descendants of the videodisc will provide us with libraries, about 40,000 volumes, on portable computers the size of a notebook. The economic savings represented by this, compared to the cost of a 40,000 volume library of print material, is quite impressive. Every classroom will be able to store dictionaries, encyclopedias and other common reference materials on a disc, and each school will be able to afford a substantial central library. Not only will they be more accessible, but dictionaries and encyclopedias can become much more informative in videodisc form than they are in their current printed versions. Students will not just read about Niagra Falls or the White Kangaroo of Australia--they will look at them as well.

Modes of Access. Direct access to stored information represents the simplest use of the computer. Computers are able to store large volumes of material and retrieve them on command. In the classroom, the computer may also make suggestions. For example, if a student asks for information about Brazil, the computer might ask, "After you look at the material about Brazil, would you like to see some information about neighboring countries such as Argentina?" In this way the computer may stimulate the student to broaden his/her interests.

Computer-based resource materials could make use of branched menus where materials are arranged in an outline form. Initially, the student may select the topic "Brazil," then look for the subheading "food," then look for the next subheading "regional," and so on.

If the student wishes to browse, the computer could randomly select material from its memory files and display titles and/or brief descriptions on the screen. The screen might ask, "Would you like to read more about this, would you like to see more titles, or would you like to go on with your work?" This is somewhat analogous to browsing in a library when you have no particular purpose in mind. The student is simply looking for something interesting.

As a student works with the computer, the computer may gradually build up a profile of his/her interests. This profile could then be used to modify the probability of a given kind of browsing material being brought to the student's attention.

Information, Resources, and Curriculum. The curriculum is influenced by the cost of information. As mentioned previously, the observable fact is that the formal curriculum of the schools is heavily weighted toward verbal, symbolic learning. It is also oriented toward declarative knowledge as opposed to procedural knowledge. The procedures that are taught are largely those involving the manipulation of words, symbols, and line drawings. Often students are required to manipulate words and symbols when they have little or no basis in experience to give those words and symbols and symbolic operations (e.g., math) meaning.

Words and symbols are low in information content, although they have the power to evoke rich representations or memories when we have relevant experiences to be triggered. A page of print can be represented in a computer by about 15,000 bits. (A bit is the smallest element of computer code--similar to a dot or dash in Morse code.) On the other hand, a single picture on a television screen requires about 333,000 bits! Thus, a picture includes about 20 times more information than a printed page. A half hour of television requires 54,000 individual pictures or about 20,000 million bits of information, while a moderate sized novel can be encoded by about 10 million bits.

We observe that object- and image-rich learning environments tend to be allocated to professions that have the highest value in our society (e.g., the fine arts, medicine, science, engineering, computing) and certain important vocational areas such as piloting an airplane. Even here, the most intensive use of equipment and objects--because they are expensive--tends to be reserved for the "survivors" of the school system and provided just before the individuals actually go to work--i.e., when the apprentice is about to give society a return for its investment.

Perhaps it is true that this pattern of emphasizing words and symbols in early education is optimal. But the observable facts argue against this conclusion. For example, the children of affluent parents grow up in environments that are rich in toys, objects, equipment, images, travel, and so on. The schools, also relatively enriched, then provide the words, symbols, and intellectual skills to help these children organize and think about their rich base of experience. (The affluent child also gets a boost of a rich supply of words at home.) Society has come to the conclusion that children of affluent families are advantaged while children of non-affluent families are disadvantaged.

The fact of the matter is that three-dimensional models, machine shops, audio-visual equipment, materials, and field trips are expensive. The schools are driven to emphasize words and symbols because they cannot afford anything else. Only a small fraction of the school budget is available for anything except salaries and most of that is expended on textbooks.

Reading, writing, and arithmetic are essential components of education in modern society. But surely we would like our children to learn about science, music, environmental design, and many other subjects involving complex procedural skills. If our premise is correct, the only reason such skills are not woven into the curriculum is because of the cost of the materials and equipment. Learning of abstract, symbolic knowledge would be likewise enhanced by a better balance between images and symbols. It also suffers because of the cost of the images.

The combination of the computer and the videodisc will enable us to introduce procedural learning and graphic images into the schools economically. If we are correct, excellent materials will be produced for the "intelligent" videodisc, and procedural knowledge and illustrations will gradually become part of the formal curriculum. We will be able, for the first time, to search for the optimal balance between procedural skill and declarative knowledge, between observations of actual events and symbolic representations of them.

IV

Status and Potential[3]

Technological Limitations

In the previous sections we've outlined many advantages provided by the computer and videodisc. Here we consider some of the difficulties. Computers, today, are not very intelligent. As Christopher Evans said in The Micro Millenium (1979), the intelligence of present day computers may be compared to that of an earwig. He also suggests that computer intelligence is evolving rapidly and may soon, say by 1990-2010, exceed human intelligence along many dimensions.

At present, however, memories are limited. This means that programs are necessarily limited in size and the data base that a computer can use to interpret a student's action is limited in scope. The memories of most computers aren't even comparable with those of infants.

Computers also have limited graphic and image capability because of the vast amount of digital memory it takes to store pictures. The videodisc is a partial solution to this problem, as it does provide realistic representations; but the videodisc does not permit the flexibility of image manipulation, as in enlarging and reducing diagrams.

The creation of computer languages is a relatively new skill, one that is still in its infancy. Perhaps as a result, good (intelligent) programs seem, to these observers, to grow very slowly. Education has not yet attracted much attention from computer manufacturers and developers. Most programming talent has been devoted to military, industrial, and commercial development--not the development of programs for education. As a result, educational computer programs are being developed more slowly than is necessary or desirable. Education, as is usually the case, must try to make use of programs that have been developed for other purposes. For example, word processing and speech synthesis programs are available to education because they were developed for commercial applications. Similarly, voice recognition programs will eventually be available for such subjects as early reading instruction because they are being developed to replace typists who transcribe dictation tapes.

Technology and Organizational Structure

Every large, long-lasting enterprise has an organizational structure that reflects and supports its dominant technology. The organizational structure of a successful enterprise helps people to be productive with the dominant technology. Successful organizational structures tend to be stable. They resist change even when change is crucial to their ability to survive. The organizational structure of the schools helps people to be productive with classrooms, blackboards, textbooks, and homework assignments. It is not appropriate for the large scale use of computers and videodiscs. Conversely, one of the least disturbing ways to introduce the computer into today's schools is as (a) a kind of powerful electronic blackboard for the teacher (see recommendations below) and (b) as a homework tool for the students.

If we want to use computers extensively, we will be required to think through a new organizational structure that is centered on helping teachers to be productive with the computer, and transitional structures that can help us move from here to there.

Talent, Investment Costs, and Research

To capitalize on the computer and videodisc in education, we need more and better talent authoring technologically based instructional materials, better programming and programming languages for educational as opposed to commercial purposes, and more research on learning in a technological environment. Very limited investments are being made in these areas. As we move into the electronic age, we seem to be losing confidence in our ability to improve education to produce people who are knowledgeable. We have a multitrillion dollar economy and a 150-billion dollar educational system. Yet we are unwilling to invest in the training of talent, the development, and the research that could help us prepare society for the accelerating pace of change.

The problem of producing people who can design and write effective instructional materials for the new educational technologies is unsolved. Deep knowledge of a subject, knowledge of the learning process, and artistic and practical skills are needed to create written, visual, and audible materials. Very few individuals have all these skills, and we have no programs either to train such people or to support them after they have been trained. When we assemble teams of people in order to obtain the requisite combination of skills, they tend to be unwieldy and expensive. This issue needs serious national attention.

It is difficult to identify important elements of events in familiar contexts. Studies in unusual settings (e.g., observing South Sea Islanders) can help elucidate the critical elements. Efforts to develop a theory of learning and developmental projects in computer-based education could be of great mutual benefit in this regard. The theories could guide developments, and the results of development projects could provide opportunities for testing theories. Very little work of this kind is taking place in our educational research centers of anywhere else.

Conclusion

Licklider (1980) has estimated that education needs an R & D budget of $1 billion a year to make effective use of the new technologies. Without resources of this order our computer-based materials will always be a pale shadow of what they could be and what is needed. Although the figure of $1 billion seems extremely large, remember that it is less than one percent of our yearly expenditure on education and a tiny fraction of our gross national product. Furthermore, the future of our economy depends on productivity, and productivity depends in many complex ways on the quality of education. Society is an inverted pyramid with the large base of the economy resting on the much smaller educational system, and the educational system resting on a tiny vertex of knowledge and development effort. And the base is crumbling out from under us because of the inadequate investment in R & D.

New computer developments will become available because they have large commercial implications. Because of our inadequate educational system, the Japanese will gradually move into a dominant economic position--particularly in the field of computer and robot construction and related electronic and production fields. When new developments--small portable and powerful computers, optical character readers, voice recognition, the digital videodisc--become inexpensive the schools will attempt to make use of them. Schools will lag behind because of inadequate investment in research and development and an organizational structure that is inappropriate for the new technologies. In the meantime, the affluent will increasingly make use of computers while the large mass of students are deprived of adequate access to them.

Footnotes

[1] Collins and Stevens (1980) do not use the term "runnable models," but their report contains an up-to-date version of Collins' ideas.

[2] Quotation remembered from a Quarterly Report of the PSSC curriculum development project during the 1960s.

[3] A very recent paper by Henry Jay Becker (1982) addresses this theme.

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