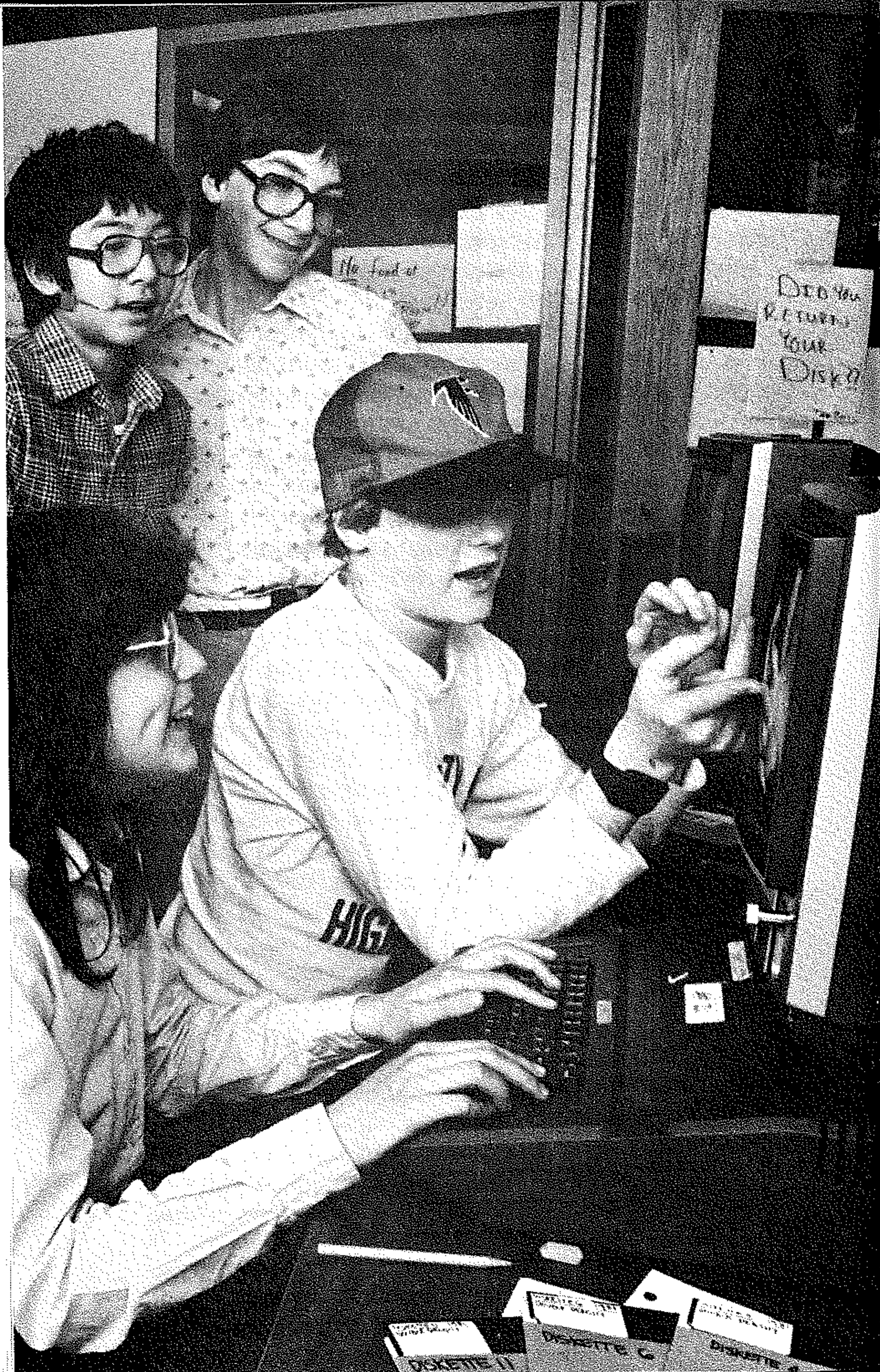


8 / Computers

Computer circuitry that in the 1960s would have cost hundreds of thousands of dollars and taken up roomfuls of space can now be made for less than a dollar and has been miniaturized to a quarter of an inch. Corresponding to these changes, there has been a dramatic increase in the availability of small computers to the general public. Children seem to be particularly attracted to this technology. Video games have become a mass (and very controversial) activity. In a time of limited budgets, schools have been purchasing computers like mad; more than half of all schools in the United States now have them.[1] Computer camps have sprung up all over the country, and many children (18 percent in California, according to an estimate by the California Department of Education)[2] have computers available at home—not just game machines but real programmable computers. Thus, computers have become an important medium in the lives of children.

THE TELEVISION CONNECTION

As with video games, part of the reason computers are so attractive to children may be children's experience with television. The link between television and computers appears to be noticed by children themselves. In a series of interviews done for a film about computers and children, one child said of computers: "It's like learning and watching a television at the same time." Others mentioned differences between television and the computer closely related to the differences between television and video games I mentioned in the previous chapter. For example, one boy said, "TV, it does what it wants to do. A computer does what you want it to." Another child's comment was similar: "It's fun because you get to control it. TV controls itself." Television has been accused of depressing the imagination; one boy saw computers as being different from television in this respect: "With TV you don't have to talk; you don't have to picture anything in your head."[3]

The children were unanimous in their preference for computers over television, just as the children I interviewed preferred video games to TV. (Children interviewed in the film had used computers for games, as well as for other functions in their classroom.)

The psychological interrelatedness of television and computers was first impressed upon me at home. When we got a home computer, the amount of time my son spent watching television decreased markedly. A case study of two other children, done by Yaakov Kareev, confirmed my observation.[4] A possible interpretation of this is that children love the visual dynamism of television, but that they prefer an interactive participatory role to a passive one. This is basically an extension of my argument in the last chapter from video games to computers in general.

Dean Brown, a pioneer in the development of computer technology, has called the computer the most astounding invention because of its unique combination of features: it is (1) dynamic, (2) interactive, and (3) programmable.[5] Unlike print, radio has auditory dynamism; it can present sound in real time with all its dynamic qualities. Television and film add the quality of visual dynamism. However, they are neither interactive nor programmable. The computer builds upon the dynamism of television, but adds these two qualities.

The interactive quality of the computer can be illustrated very simply with video games: the player affects what happens on the screen, and developments on the screen, in turn, constrain the possibilities for the player's next move. Thus, control and influence over the game go in two directions, from the player and from the computer. The same is true of computer-assisted instruction, where, at the simplest level, the computer poses the problem, the learner responds, and the computer gives feedback specific to that response. In a slightly more complex learning program, the learner's response can influence the choice of the next problem. As in video games, the computer provides a two-way street.

The third quality of computers, programmability, comes into play mainly with the activity of computer programming. Again, the attraction for children may grow out of their television experience. Herbert Kohl comments on what children choose to program :"I have found that the ability to compose music, develop visual images, animate figures, and control color effects are the most compelling aspects of programming for young people. In this way they can turn the tables on TV. They make their own programs instead of passively receiving someone else's."[6]

Three important uses of computer technology with children are learning software, word processing, and programming. All three take advantage of the interactive quality of the computer. However, they differ in the amount of control they allow the child user. With learning software, the computer, while responsive to the child, is definitely in charge: the computer programs the child (although the degree to which this is so varies from program to program). In word processing, the computer program furnishes a tool,[7] and the child both creates the material—text—upon which the tool works and decides how to use the tool to shape the material. In programming, the child tells the computer what to do, using a special language the computer can understand.

LEARNING SOFTWARE

Computer-Assisted Instruction. Although the line between video games and learning software has become increasingly blurred over time, the original learning programs were drill and practice programs developed under the rubric of Computer-Assisted Instruction (CAI). These programs, developed before current computer technology with its animated graphics, are essentially question-and-answer programs in which the computer poses the problem, gives the student a chance to respond, and then tells the student if the answer is right. With children, such programs are generally effective as supplements to traditional instruction, in mathematics and language arts for example.[8]

The major limitation of these programs is that they are more suited to provide practice in skills that are already present than to teach something new. Therefore, they tend to work best with students who already possess the basic skills in question. An example of this comes from a study in which a battery of drill and practice programs in math,reading, and language arts were tried out in a systematic way in elementary schools in Los Angeles.[9] Drill and practice in mathematics, where students already had basic concepts, were considerably more effective than drill and practice in reading: some

students could not read well enough to gain much from the reading program. The computer drills could help them practice reading, but they could not teach them to read. This distinction is not a hard and fast one. Drill and practice can be used efficiently to teach certain types of knowledge, such as vocabulary, that lend themselves to a multiple-choice format.

The Los Angeles study was done in an economically disadvantaged group of children, and although the drill and practice programs were more effective for some subjects than for others, children who used the computer for drill and practice did better in certain aspects of all subjects than other children from the same school who did not use the computer. This illustrates an important theme that emerges again and again: like television, computer-based learning is not only effective in middle-class environments; it also works for children from educationally disadvantaged homes. Like the earlier electronic media, computers seem to work equally well with people from a wide variety of backgrounds. Computers are also effective tools for teaching children with various learning handicaps.[10] It seems clear that computers can reach children who have not been reached by older and more traditional educational methods.

Drill and practice programs utilize relatively little that is unique to the computer. Basically, they simulate a workbook type of situation. But they do have two advantages directly attributable to the computer: individualization of questions depending on the learner's level of skill, and instantaneous feedback.

The computer's feedback is not only instantaneous; it is also totally impersonal. This is an advantage from a psychological point of view: error becomes something to learn from rather than to fear. As a seven-year-old put it, "The computer doesn't yell." Nor does it have favorites. Indeed, computer technology lowers both the real and the psychological cost of error in all areas it touches, not just in drill-and-practice software. This is important because many negative patterns of behavior in school grow out of fear of error and fear of failure.[11]

Teaching with models. Another category of learning program makes use of even more of the computer's unique capacities. This category involves model-building of one sort or another. A very simple example of using a model to teach is the game of Harpoon, designed by James Levin, in which the goal is to specify the position of a shark by estimating points on two number lines, one horizontal and one vertical. "The program asks the players to specify the position of the shark left and right and then its position up and down. After they enter the two numbers, a 'harpoon' flies across the screen to the position they have specified. If that spot is close enough to the shark, then the harpoon hits the shark, and the shark sinks out of view. If the harpoon misses, then a 'splash' occurs on the screen to mark the spot, and the players can try again, using the splash mark as feedback."[12]

The model is a representation of shark hunting in a two-dimensional model of ocean space. The game uses a spatial model to teach estimation skills involved in two-dimensional mapping from position to number. In a simpler version of the game, the shark exists in one-dimensional space and the children need estimate position on only one number line.

Levin has tested this game with ten-year-olds, who find it challenging and motivating. As for learning, results are available only for the simpler, one-dimensional version of the game. Levin reports that within ten games children move from random performance to high accuracy.

The process of learning. Perhaps even more interesting than this rapid learning are the processes, both cognitive and social, that go on as the children move toward proficiency. On the cognitive side, children often start out with their own concept of the task. For example, some children initially acted as though they thought the task was to get the path of the harpoon to *cross* the shark rather than to land on it. Thus, a thematic model (here shark hunting), while it can motivate and aid learning, may also interfere with the main learning objective (here, estimating position on coordinated number lines). At the same time, this type of situation allows children to try out different hypotheses about the nature of the task as defined by the computer program. This process of hypothesis testing is, in itself, a valuable kind of learning.

On the social side, Levin and Kareev observed the following sequence in an after-school computer club: "Initially, a child would work with other children and would also freely use adult help to learn about a new computer program. Next, children would work together without direct adult participation, only drawing in an adult to help when they got blocked in some way. Finally, a child would work either with a friend or alone, gradually making the task more challenging if the program allowed this."[13]

This sequence shows how cooperative activity can benefit learning, and how the computer can foster cooperative enterprise. Such cooperation seems to occur primarily when there are fewer computers than children wanting to use them and the computers have to be shared.[14] Thus, under certain conditions, the popular stereotype of computers as an essentially asocial technology does not apply.

The sequence also illustrates the appeal of challenge. In Harpoon, expert players would make the size of the shark smaller, thus increasing the difficulty of hitting it. As they worked with progressively smaller sharks, they developed increasingly accurate number-estimating skills. Children do not want to keep working at a level they have perfected; they seek a new challenge. Harpoon illustrates how this attraction to new challenges can be used in computer games designed for education, as it is in games designed for entertainment. This ability of the computer to keep pace with the child's emerging skills is one of its main advantages as an educational tool.

Computer simulation. The simple model of Harpoon is not, of course, intended to teach children about shark hunting. Another type of computer model, generally more complex than Harpoon, does teach about a real-life situation or system. This type of model is called a simulation. Atari's *Guide to Computers in Education* provides a good overview of the educational possibilities of computer simulation:

> The impact of different national energy policies on the economy, the survival of a herd of caribou, a scientific laboratory experiment, the economics of a small business, the setting up of a space colony, the ecosystem of a pond—virtually any system can be represented by formulae which . . . represent how all the components of the system interrelate. The simulation then allows the student to alter the condition of one or more components and see the consequences of this alteration on the rest of the system. How will unchecked waste disposal alter water quality and affect life forms in a lake? What treatment methods will most effectively restore water quality; and over what period of time? The computer becomes an infinitely variable experimental laboratory for exploratory learning.[15]

One of the first simulations to be developed for young children was called Lemonade Stand. In this simulation, you, the player, start with supplies for making lemon-

ade (provided by your mother). The program gives you information relevant to consumer demand for lemonade (such as a weather forecast), and you have to decide how much lemonade to make and at what price to sell it. The computer then calculates the profit you would make under those conditions. In later turns, your mother stops providing you with sugar, and your decision making must also take the fluctuating price of sugar into account. The point of Lemonade Stand is to maximize profit.

This simulation builds on a real-world model that is familiar to many young children, the lemonade stand. However, it should enable children to go beyond their everyday knowledge of the model to understand relationships between variables such as cost and profit, supply and demand. The computer simulation enables children too young to comprehend abstract discussions of profit, loss, and so on to learn through *doing* how economic variables operate.

It may be that this concrete, action-oriented knowledge can serve as a foundation for later understanding of the concepts on a more abstract level. Perhaps a program like Lemonade Stand not only lets children begin learning the concepts sooner (not necessarily an advantage) but later allows them to learn them more easily and profoundly, say in a high school or college economics class, for having had the experience of actively manipulating them in a concrete situation. This sequence of learning is still speculative. Research is needed to find out what knowledge children of different ages take away from simulations like Lemonade Stand and whether this knowledge can aid the later learning of the same concepts on an abstract level.

Lemonade Stand builds upon and extends children's everyday experience. Simulations can also build upon and extend topics initiated in school. A nice example of this comes from Gompers Secondary Center in San Diego, where a computer simulation of the migration of the California gray whale, written by the San Diego Department of Education, is used in class after the annual whale-watching field trip. The computer provides another medium in what is already a multimedia experience, combining classroom discussion with actual observation.[16]

What is the value of augmenting observation with computer simulation? This question was systematically explored in a study that looked at the role of computer simulation in teaching high school physics.[17] Experiments were set up that could be done either in the laboratory or on the computer. One group of students did the experiments on the computer only, one group in the laboratory only; the third group combined computer and lab, doing one trial of each experiment in the laboratory as an example, but using the computer to collect data for analysis. The combination of computer and lab was most effective for the largest number of outcome measures: this group was able to reach conclusions more effectively and had the highest exam scores. The computer alone was most effective in teaching how to investigate relationships between laboratory variables. (This is a higher-level version of what should result for younger children engaged in Lemonade Stand.) The laboratory-only group was not superior to the other two groups on any outcome measure. Thus, the computer is no exception to the principle, which I will emphasize in the next chapter, that a multimedia approach to a topic is often the most effective one.

The program that learns. Programs that learn are unique to the computer medium and derive directly from its programmability. An example of such a program is a game called Animals, which illustrates the possibilities of learning games that put the player rather than the computer in charge. The game is modeled on the old game of twenty questions. The twist is that the computer starts out knowing only two animals and the player has to teach the computer the names and characteristics of other animals he or she wants to introduce into the game. Essentially this game teaches the logic of class relations while at the same time requiring the player to create a logically structured domain of knowledge. The player creates the knowledge that the computer then uses to play the game. Animals exemplifies how, unlike reading, radio, or television, interactive computer technology can give the child the active role so crucial to the learning process.

WORD PROCESSING

This book was written using a word processing program for an Apple II Plus computer. Thus, as Seymour Papert has pointed out, word processing is an adult, even professional use of the computer that is available to children.[18]

Word processing was my first personal involvement with computers. I was impressed by the changes it made in my thought processes and productive ability: I felt that I could write more quickly and more easily; revision became a pleasure rather than a chore. I was sure the effects must be at least as dramatic for children, so I set about looking for people doing research relating to children's use of word processing. As with the whole area of children and computers, there has not yet been much systematic research on what happens when children have access to word processors. Not all the people I talked to in the field agreed that the effects are dramatic, but I found more agreement about positive effects in this area than in any other I researched for this book.

In word processing (also called text editing) you write at a computer keyboard, much as you would at a typewriter. The difference is that you see your initial product on the video screen rather than on paper. Because the text you create is in the computer's memory, as well as on the screen, you can make changes electronically, without any need for physically erasing or crossing out. You can even "cut and paste" electronically, moving words, paragraphs, or pages from one part of the text to another with a few keystrokes. The cost of error is reduced to insignificance. In order to get "hard copy" (words typed on paper), you hook up the computer to a printer which puts the text stored in memory (and later transferred to cassette tape or disk) into typewritten form. You give electronic commands, via the computer, for the format of the printed page—margins, underlining, and so forth. You can print out a given piece of text in a different format without retyping it, by simply changing the format commands. Similarly, you can revise the text without retyping, by merely going back to the original version, saved on tape or disk, and electronically revising it.

My first concrete evidence relating to children and word processors came from Jan Austin, an elementary school teacher in northern California. She had given her third and fourth graders the project of writing a book about Native Americans on the computer. The class successfully wrote the book, which they then distributed to other people. This by itself was notable, for it was a much larger writing project than the class had undertaken before. Even more important, it was the best writing the class had done all year. It had depth—because, as Austin eloquently put it, "the children were released from their scribal labor."

One important reason for the improvement in the quality of the children's writing was their willingness and even eagerness to revise, made possible by the ease

of electronic revision on the computer. The children revised the text of their book many times. They also got interested in spelling, and in experimenting with print formats. They tried many different formats, and the teacher finally had to insist that they stop experimenting and produce the final product. Even then the children complained that if she had given them just one more day they could have produced a much better book. And these were children who, before the computer, had to be begged to make even the most minor revisions.

The computer also encouraged cooperation among children in the writing project. According to their teacher, this class had had some trouble getting along with one another, but the computer drew them together. There were always three or four children standing around the computer working together on the book. This theme that computers foster cooperation is one that we have met before. But when each child has a computer to write with, they become so involved in writing itself that this sort of cooperative activity does not take place.[19] It seems to be the need to share computers that prompts children to work together.

One way computers can, under the right circumstances, foster cooperative intellectual work is apparent in word processing. The screen makes an individual's thought processes public, open to others who can also observe the screen. It makes writing into an easily observable physical object, which can be manipulated in various ways by other people. Thus, the computer makes the private activity of writing into a potentially public and social one.

It may be that group writing, with its stimulus of other children's points of view, is also necessary for word processing to lead fairly quickly to extensive revision. Researchers at Bank Street College of Education in New York found that eighth graders who used word processors for individual compositions tended to treat the computer like an electronic pencil and paper: they spent time planning their writing in advance and did not do much revision. Nevertheless, even here the children reported doing more spontaneous revision than they normally did without a word processor. Perhaps more important, in the long run, than spontaneous revision is the fact that, when students have access to a word processor, the teacher may *ask* for more revision.[20]

Another interesting point that emerged from the work at Bank Street was the usefulness of word processing for a child with behavior problems. This child had been introduced to word processing in a course and enjoyed it so much that she pursued it after the course was over. In other settings, learning-disabled students have improved their writing skills markedly when given the chance to write on a computer.[21]

High school students seem to be as enthusiastic about word processing as younger children. (Indeed, according to Midian Kurland, children love word processing so much that even lack of typing skill does not deter them.) Julie McGee, director of computer curriculum development at Lyons Township High School in Illinois, reports that students are fascinated by the word processor and are motivated to learn how to use it.[22] Because the computer makes writing less painful, they *want* to write. They are more willing to revise and to correct their mistakes. McGee has also found the word processor useful for group work: her students are using it to produce their yearbook. Like younger children, they enjoy having a typed product, and they help each other with work.

I have had every one of these reactions to writing with a computer, and it would surprise me very much if they did not also apply to other adults. Indeed, professional writers have been attracted to word processing in droves.

In July 1982 the *Los Angeles Times* ran an article about a center to which people can go to rent extremely powerful word processing equipment at an hourly rate. The headline was "A Word-Processing Romance: Center Provides Hourly Rental to Infatuated Users." One customer, Philip Friedman, a successful screenwriter, said,

> I do things here I wouldn't otherwise do . . . You can move stuff around very easily. You can make all kinds of small changes which would require retyping an entire manuscript. You get to create a very visual effect and that's very important. All of this becomes fine tunable in a way that would be impossible unless one is willing to employ a whole platoon of typists. It allows a loosening up for me. It makes me more willing to try different things. It allows me to be more confident and feel like it's going to turn out all right.[23]

Although data are not available to make a direct comparison, the basic effects of word processing seem to be parallel in many respects in children and adults.

Most of the projects with young people mentioned so far are in the midst of controlled studies to assess the effects of word processing on writing, but results are not yet in. One such project, however, has already obtained some important findings. James Levin and his colleagues compared two classes of third and fourth graders: one class had spent four months working with a special word processing program designed for children; the other had had only the writing experience that normally takes place in school. At the beginning and again at the end of the four months, each class was given a topic to write about (with pencil and paper, not a word processor) in a restricted time period. The "before" and "after" writing samples were analyzed for length (number of words) and for overall quality (with an emphasis on adherence to topic and organization).

The researchers found an increase of 64 percent in the number of words in the essays of the class that had worked with the computer; the essays of the other class showed no increase. In addition to quantity, the results also showed a gain in quality as a result of the computer: on a five-point scale of quality, the class exposed to word processing increased from an average score of 2.00 to 3.09, while the other class showed no change in quality ratings.[24] (We do not know to what extent these results were caused by more writing practice in the class with the word processor, and to what extent they were caused simply by using the word processor. However, since the availability of a word processor causes students to spend more time writing, either way the results constitute an effect of word processing.)

These findings, in fact, probably underestimate the effect of the computer, for they are based on writing *without* a computer. I would think that the effect would be stronger if the children trained on the computer were assessed writing on the computer. The comparison used in the study is fairer to the children who were not given computers to use, but it does not reveal the actual power of the computer as a writing tool. I have had the subjective experience reflecting the findings of this study. After writing on my computer for a while, I seemed to be able to compose on a conventional typewriter better than before. But I could write much less fluently and revise less easily on the typewriter than on the word processor itself. The power of a tool can be seen most clearly in the work accomplished with it, not in work done without it.

Levin and his colleagues also studied the cooperative process around word processing in detail. They had children work together in pairs and found great benefit from doing so: "Often when one child encounters a block in writing, the other child, bringing a different point of view, can solve the problem by suggesting an alternative approach. The first child not only benefits from having the immediate problem solved, but is exposed to alternative ways to think about the task."[25] Working in pairs also greatly reduced demands upon the teacher's time. Most of the problems that arose for one student could almost immediately be handled by the other, so the teacher did not have to step in. This freed the teacher to use his time in providing support tailored to the students' individual needs.

This study demonstrates that the computer and the cooperation it elicits allow the teacher to individualize instruction more than conventional methods do, adapting tasks to the needs and skills of different children. As a student gains more experience, the teacher's help can be progressively reduced, thus providing a system of "dynamic support," help that changes as the learner's needs change. The computer itself can also provide individualized and changing help, in the form of more or less structured writing tasks. For example, novice writers were given fill-in-the-blank stories to work on, intermediates were assigned unfinished stories to complete, and advanced writers could start from scratch. This individualization of teaching is a powerful factor in the value of computers for learning.

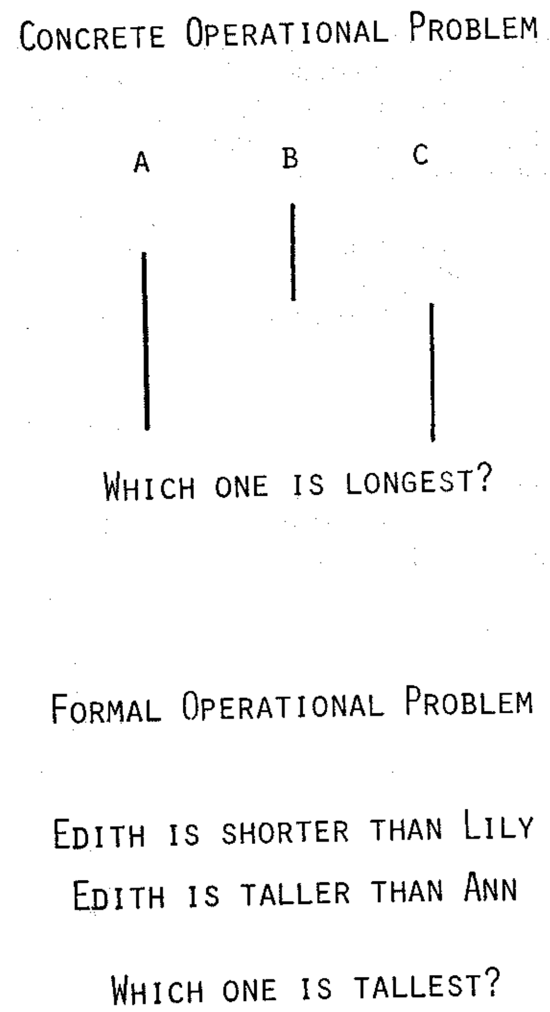
Seymour Papert, in his book *Mindstorms,* points out why word processors can make children so much more enthusiastic about writing:

> For me, writing means making a rough draft and refining it over a considerable period of time. My image of myself as a writer includes the expectation of an 'unacceptable' first draft that will develop with successive editing into presentable form. But I would not be able to afford this image if I were a third-grader. The physical act of writing would be slow and laborious. I would have no secretary. For most children rewriting a text is so laborious that

the first draft is the final copy, and the skill of rereading with a critical eye is never acquired. This changes dramatically when children have access to computers capable of manipulating text. The first draft is composed at the keyboard. Corrections are made easily. The current copy is always neat and tidy. I have seen a child move from total rejection of writing to an intense involvement (accompanied by rapid improvement of quality) within a few weeks of beginning to write with a computer. Even more dramatic changes are seen when the child has physical handicaps that make writing by hand more than usually difficult or even impossible.[26]

Word processing and thinking. Far more speculative than the effects of word processing on writing are its effects on thinking. In 1969, Sylvia Scribner wrote a provocative paper about the cognitive effects of literacy, in which she argued that literacy is a necessary factor in the development of Piaget's highest stage of cognitive development, the stage of formal operations.[27] One way formal operations are distinguished from the earlier stage of concrete operations is by the ability to rearrange propositions or statements mentally. At the earlier stage, children can mentally rearrange concrete objects, but not abstract statements. For readers unfamiliar with Piaget's theory, figure 8 shows the same problem presented at both a concrete and a formal operational level.

This hypothesis about the effect of literacy on formal operations goes back to a key idea of Piaget's: that cognitive development is a product of the child's active manipulation of the world. This is clearly possible for concrete operations, where the child can manipulate concrete objects. But how could it apply to the abstract skills that are the essence of formal operations? Scribner's answer was writing, a process in which propositions or statements are given an external form, which then allows them to be rearranged in the process of



8. *A seriation problem at two levels of cognitive development.*

revision. She noted that formal operations have never been observed in nonliterate cultures. She also cited some data indicating that they do not occur in people with less than a high school education. Yet clearly basic literacy and even a high school education are not sufficient, because a substantial proportion of American college students have not yet attained the stage of formal operations as measured by Piagetian tests.

My hypothesis is that not all high school or college students have enough experience with revision, the process of rearranging text, to be able to solve problems of the sort illustrated at the bottom of figure 8. I believe word processing can provide just this sort of experience to many more people. Therefore, I predict that as writing by computer becomes more widespread it will lead to better performance by a larger proportion of the population on the type of formal problem involving the mental manipulation of abstract propositions.

Composing on the word processor is not enough in itself to lead to formal thinking; practice in revision is necessary. Even in eighth grade, only a small minority of children actively rearrange text when taught to use a word processor. Revision may be more frequent at older ages and in groups. Once word processing equipment becomes more widely available, teachers will be able to encourage students to do more revising. My hypothesis about the effect of word processing on formal operations applies only when the word processor is in fact used to rearrange text in the editing or revision process.

Cognitive requirements for word processing. As mentioned earlier, the basic mechanics of word processing are very easy for children. A study of adults sheds some light on what skills children may possess that make word processing easy: the ability of adults to learn to use a word processor was found to be related primarily to their spatial memory and secondarily to their age.

The better a person's spatial memory (for arrangements of objects), the easier it was for the person to learn to use the word processor. Similarly, the younger the person, the easier it was to learn.

Recall from earlier chapters that children gain spatial skills by watching television. The importance of spatial memory for word processing gives a clue that the skills picked up from television may facilitate working with word processors in particular and computers in general. Although this was a study of adults, the age factor does hint that children may have an advantage over adults in learning to use computer technology, whether this advantage derives from their greater flexibility or their experience with television.

In word processing the medium of print is placed in the context of a new medium, computers. As print decreased in importance relative to the electronic media, writing skills are said to have declined. It will be interesting to see, as computers become more widely available, if the word processor, with all the freedom it gives a writer, will reverse this trend.

PROGRAMMING

Some of the most optimistic thinking about the educational potential of computers focuses on computer programming.

In France, an official government policy report labeled computer programming a "crossroads discipline" comparable in importance to mastery of one's native language and of mathematics. It was proposed that computer science become a compulsory subject in secondary school, with 200 hours of instruction distributed over 4 years. Many educators and parents in this country might endorse such a proposal. The reasons given go beyond the

> pragmatic employment value of computer skills. As it was once popular to think about the learning of classical languages, computer programming is often considered to be a source of mental discipline that has widespread cognitive consequences. It compels the orderly and precise description of the actions that are required to attain a desired goal; for computers lack the inferential comprehension skills that permit vagueness to succeed in everyday human communication.[30]

As Papert puts it, he wants to see the child program the computer, rather than the computer program the child. And some children do take to programming with enthusiasm. Early reports in the popular press sensationalized child programmers. For example, *Money* magazine ran an article in 1982 about adolescents earning good livings as part-time programmers and software designers. The youngest children featured in the article were two 12-year-old boys who designed a record-keeping program and then set up a company to market it.[31] However, while most children show themselves capable of learning to program simple commands, observations in the Bank Street School indicate that only about 25 percent of all third- and sixth-grade children are highly interested in learning to program. Another quarter are quite uninterested and learn very little. (These results relate to one particular computer language, LOGO. While no research on this yet exists, Sherman Rosenfeld has pointed out that the unstructured aspect of BASIC may be easier than LOGO for young children whose cognitive development does not yet enable them to deal with certain complex logical structures.)

When children do complex programming, video games are their favorite subject.[32] Thus, the games have an important benefit in addition to those mentioned in the previous chapter: they provide motivation for learning programming. Beyond motivation, experience in playing the games should furnish sensorimotor knowledge of what to program. Programming games is a good first step in the symbolic conceptualization and manipulation of complex systems. Because more abstract skills build on practical, sensorimotor experience, video games can furnish a solid foundation for the symbolic representation of complex, interactive, dynamic systems.

A computer program is basically a systematic set of instructions for the computer. The instructions must be written in a special language that the computer understands. LOGO is one such language, designed especially to introduce children to programming. It was developed by Papert and his colleagues at MIT. Because the computer cannot make inferences, the instructions must be completely explicit. As a ten-year-old at the Bank Street School said about the computer: "It's dumb. I have to tell it everything."

This quality has an important positive side as well. One potential effect of the computer's need for explicitness is to make procedural details that are implicitly taken for granted in everyday life explicit and therefore conscious. Papert gives a nice example of this from turtle geometry, a system for learning geometry by programming the visible path of an entity, called a turtle, using the LOGO language. Say a child wants to program his turtle (visible on the computer screen as a triangle of light) to make a circle. The child is first asked to "play turtle," to move his body the way the turtle must move to make a circle. This might lead to a description such as "When you walk in a circle you take a little step forward and you turn a little. And you keep doing it." The next step is to express this description in programming language: TO CIRCLE REPEAT (FORWARD 1 RIGHT 1).[33] This program or set of instructions tells the computer to move the triangle one unit ahead, one to the side, and keep repeating this sequence. The child who gets to this point has become conscious in a new way of what it means to walk in a circle. Such awareness is necessary for the child to program the computer, although it was not necessary for the child to program him or herself to walk.

A careful study of children and teachers using LOGO indicate that the steps in such a sequence do not happen spontaneously. There is need for a more structured instructional context than Papert advocates.[34] As with print, exposure to the medium itself is not enough for particular skills to develop; just as children have to be taught to read, they need instruction in programming computers.

Papert's example can be used to illustrate another important point. This program for generating a circle is based on differential geometry, a type of geometry that is part of differential calculus. It contrasts, for example, with a computer program based on Euclidean geometry, where the circle is defined in terms of a constant distance of all points from the center. Euclidean geometry is usually taught several years before differential calculus. The computer makes possible an inversion of the order of learning the two geometries. Papert believes that computer programming may make what have been considered very advanced cognitive skills possible at much younger ages. While claims such as these are provocative and have generated much interest, there is as yet little relevant scientific evidence.

Effects of programming. The same study of classes using LOGO found that pupils gained in general computer literacy from a year of experience with LOGO. They knew more about the uses of computers, for example, and they understood that a computer needs very literal and explicit instructions. They could also discuss the relative advantages and disadvantages of two different computers for different programming functions. This

kind of knowledge will be useful for adults in the future, who will come into frequent contact with computers, whether or not they program them themselves.

Is there any hard evidence that what children learn from programming transfers to other cognitive skills? Such evidence would be required to substantiate the claims made in the French government's policy report. There is some evidence that computer programming can help children learn mathematics. For example, learning to write programs to generate and print number series helped eleven-year-olds to solve problems involving the mathematical concept of a variable.[35]

LOGO programming has also been used to impart physics concepts. Andrea DiSessa and Papert taught physics in the MIT Artificial Intelligence Laboratory using a modified version of the turtle, called the "dynaturtle." The dynaturtle looks like the turtle used in geometry, but its movement follows the laws of physics rather than those of mathematics.

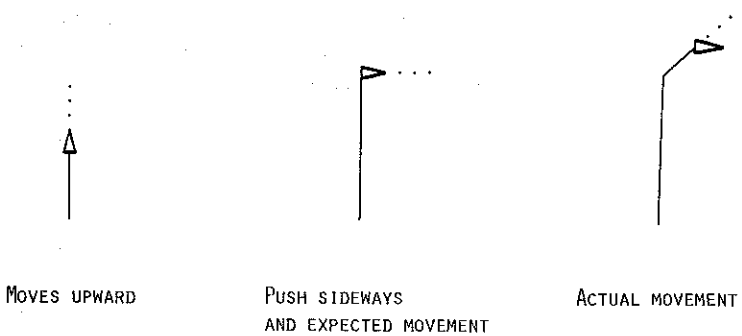
> In the dynaturtle environment, students control the motion of the turtle by 'pushing' it with forces of specified direction and magnitude. The turtle then moves on the screen according to the laws of Newtonian physics as if it were an object on a frictionless surface.
>
> One of the first surprises students have in this environment is that the turtle doesn't always move in the direction they push it. For example, if the turtle is moving upward and the student wants it to change direction and go sideways, he cannot just give it a sideways push. Instead, he must give it a push with a direction and magnitude that completely counteract the upward motion and also impart a sideways motion.[36]

Figure 9 illustrates the difference between the way a student might expect the dynaturtle to move and the way it actually does move when given a sideways push.

The dynaturtle can be used to impart an intuitive understanding of elementary mechanics that is very hard to get in traditional learning environments. One reason is that frictionless surfaces are not generally available. The relative ineffectiveness of the more usual methods of teaching physics for transmitting this set of concepts is demonstrated by the fact that MIT physics students who played with the dynaturtle did almost as poorly as elementary school students.[37]

There is only one real piece of evidence of transfer from programming to a general cognitive skill that has no direct connection to the programming: after a year of LOGO, nine- to eleven-year-old children did better on a word puzzle and a permutation task than a comparison group without programming experience.[38] The permutation task (in which the child is asked to rearrange a set of elements in as many ways as possible) has special significance because permutations and combinations are part of formal operational thinking. For this reason, it constitutes a piece of support for Papert's claim that, by making the abstract concrete, programming will develop formal operational skills.

Programming and social interaction. The world of turtles and dynaturtles may sound like a solitary and mech-



9. *An error in a student's conception of motion. (Adapted from DiSessa, "LOGO Project, Massachusetts Institute of Technology.")*

anistic one, without human contact, in which individual students sit alone and stare at video screens. Many people seem to think of computers in this way. To investigate the impact of computer programming on children's social contacts and interaction, Bank Street researchers observed children aged eight to eleven in classrooms where they were learning to program in LOGO. The researchers observed the children both when they were working with computers and when they were engaged in the more traditional classroom activities. (The opportunity for interaction was available in both types of situation because all observations were made in work periods, which were not directed by the teacher.) The children collaborated more with each other, both verbally and nonverbally, when they worked with computers than when they engaged in other activities.[39] The surprising sociability of computer activity, at least in the classroom, is a theme that has come up over and over in my research for this book. It seems that the common fears about the dehumanizing or mechanizing influence of the computer may be at least partially unfounded and that the computer's effect in the classroom may generally be quite the opposite.

LOOKING TO THE FUTURE

In the words of O. K. Tikhomirov, "Just as the development of gasoline engines provided a tool for human physical activity, so the development of the computer provided a tool for human mental activity . . . Tools are not just added to human activity; they transform it."[40] Will the computer, as Tikhomirov claims, truly transform mental activity? In the one area where computers are most fully functioning in the capacity of a tool—word processing—they do seem to be transforming the child's (and the adult's) relationship to writing. Perhaps when all is said and done, the computer's biggest contribution to education will turn out to be a motivational one: computers capture the interest of students who would normally be dropouts from the educational system. At Garfield High School, in the middle of the Latino barrio of Los Angeles, the rate of absenteeism for computer classes is less than 5 percent, compared with 20 percent for the school overall. Students not only come to class, they also stay after school and come back on Saturdays to do computer work. An important tribute to the motivational power of the computer comes from a student, Margarita Vargas: "Students are more interested in working on computers right now than in spending time on the streets."[41]