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Four-year-old Leah was playing Thinkin' Things (Edmark Corp., Redmond, Wash.) (fig. 12.1). She needed to find a "fripple with stripes and curly hair but not purple." She had the mouse posed over a purple fripple and said, loudly, "Not purple!." Then she moved to a green striped fripple and said, "Ha! I think *this* is the right one? No!" After another search, she hovered over a correct choice. "Is this one? Yes! then I click on it." Leah's talking aloud indicated that she is not only learning about attributes and logic but also developing thinking strategies and "learning to learn" skills.

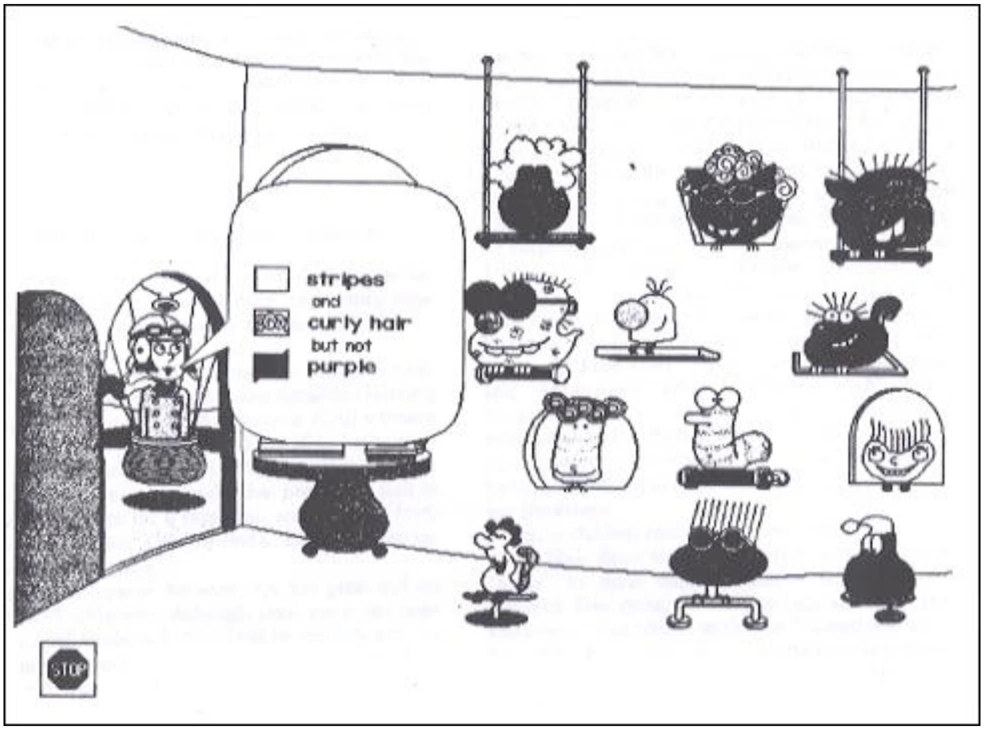

Fig. 12.1. The person at the door asks the child to find a "fripple" with certain attributes. If the child clicks on a fripple without those attributes, an announcer intones, "That fripple is not exactly the one the customer wants!" If the fripple is correct, it bounces through the door. The program records the level of difficulty the child was on, so that appropriate problems are presented in the next session. (Published by Edmark Corp., Redmond, Wash.)

Technology can change the way children think, what they learn, and how they interact with peers and adults. It can also "teach the same old stuff in a thinly disguised version of the same old way" (Papert 1980). The choice is ours.

Changes in Perspectives

Just a decade ago, only 25 percent of the licensed preschools had computers. Now almost every preschool has a computer, and the ratio of computers to students has dropped from 1:125 in 1984 to 1:22 in 1990 of every preschool; also, the amount of time children use these computers may vary widely. We can, nevertheless, expect most children to have one or more computers in their preschools and homes in the twenty-first century. We must think carefully, however, about how we choose to use computers with preschoolers.

During the current decade, research has moved beyond simple questions about technology and young children. For example, no longer need we ask whether the use of technology is developmentally appropriate. Very young children have shown comfort and confidence in using computers. They can turn them on, follow pictorial directions, and use situational and visual cues to understand and reason about their activity (Clements and Natasi 1993). Typing on the keyboard does not seem to cause them any trouble; in fact, it seems to be a source of pride. Thanks to recent technological developments, even children with physical and emotional disabilities can use the computer with ease. Besides enhancing their mobility and sense of control, computers can help improve self-esteem. One totally mute four-year-old, diagnosed with mental retardation and autism, began to echo words for the first time while working at a computer (Schery and O'Connor 1992). However, access is not always equitable; children attending schools with high poor and minority populations, for example, have less access to most types of technology (Coley, Cradler, and Engel 1997).

Further, the unique value of technology as a learning device is no longer in question. For instance, by presenting concrete ideas in a symbolic medium, the computer can help bridge the two. Research shows that what is "concrete" for children is not merely what is "physical" but what is *meaningful* (Clements and McMullen 1996). Computer representations are often more manageable, flexible, and extensible. One group of young children learned number concepts with a computer felt-board environment: They constructed "bean-stick pictures" by selecting and arranging beans, sticks, and number symbols. Compared to a real bean-stick environment, the computer environment offered greater control to students (Char 1989). The computer manipulatives were just as meaningful and easier to use for learning.

Learning Mathematics and Science

All this does *not* mean, however, that all computer experiences are valuable. The "valuable" experience most often depends on the computer software children are using.

For all types of software, the research picture is moderately positive. Young students make significant learning gains using computer-assisted instruction (CAI) software (Kulik, kulik, and Bangert-Drowns 1984; Lieberman 1985; Niemiec and Walberg 1984; Ryan 1991) -- more specifically, the type of software that presents a task to children, asks them for a response, and provides feedback. Leah's Thinkin' Things -- find a "fripple" -- is an example of such software.

Most CAI programs, however, are just plain drill on number and arithmetic. Although even these can raise children's skill levels, drill should not be our only goal, or even our main one. Instead, the National Council of Teachers of Mathematics (NCTM) recommends that we "create a coherent vision of what it means to me mathematically literate both in a world that relies on calculators and computers to carry out mathematical procedures and in a world where mathematics is rapidly growing and is extensively being applied in diverse fields" (NCTM 1989, p. 1). This vision de-emphasizes rote practice on isolated facts and emphasizes discussing and solving problems in geometry, number sense, and patterns with the help of manipulatives and computers.

For example, by using programs that allow the creation of pictures with geometric shaped, children have demonstrated growing knowledge and competence in working with concepts such as symmetry, patterns, and spatial order. A child in June Wright's school, Tammy, overlapped two triangles with opposite orientations (one facing left, the other right) and colored selected parts of the resulting figure to create a third rectangle that did not exist in the program! Then she challenged her friend to make a triangle just like it. Not only did preschooler Tammy exhibit an awareness of the challenge it would be to others (Wright 1994). Using a graphics program with three primary colors, young children combined them to create three secondary colors (Wright 1994). Such complex combinatorial abilities are often thought of as beyond the reach of young children. Instead, the computer experience led the children to explorations that broadened the boundaries of what they could do.

Computers also help by providing more-powerful and flexible "manipulatives." For example, Mitchell wanted to make hexagons using the pattern-block triangle. He started off-computer and used a trial-and-error approach, counting the sides and checking after adding each triangle. Using the computer program Shapes (Dale;e Seymour Publications, Fairfield, N.J.), in contrast, he began by planning (Sarama, Clements, and Vukelic 1996): He first placed two triangles, "dragging" them and turning them with the "turn too." Then he counted with his finger around the center of the incomplete hexagon, visualizing the other triangles. "Whoa!" he announced, "Four more!" After placing the next one, he said, "Three more!" Whereas off-computer, Mitchell had to check each placement with a physical hexagon, the intentional and deliberate actions on the computer led him to form mental images; that is, he "broke up" the hexagon in his mind's eye and predicted each succeeding placement.

Young children can also explore simple "turtle geometry." They direct the movements of a robot or screen "turtle" to draw different shapes (LCSI, Montreal, Canada). One group of five-year-olds was constructing rectangles: "I wonder I can tilt one," mused one boy. He turned the turtle with a simple mathematical command, "L1" (turn left one unit), drew the first side, then was unsure abut how much "turning" was necessary at this strange new heading. Finally he figured that it must be the same turn command as before. He hesitated again, "How far now?. . . Oh, it *must* be the same as its partner!" He easily completed his rectangle (see fig. 12.2). The instructions he should give the turtle at this new heading were initially not obvious. He analyzed the situation and reflected on the properties of a rectangle. Perhaps most important, he posed the problem for himself (Clements and Battista 1992).

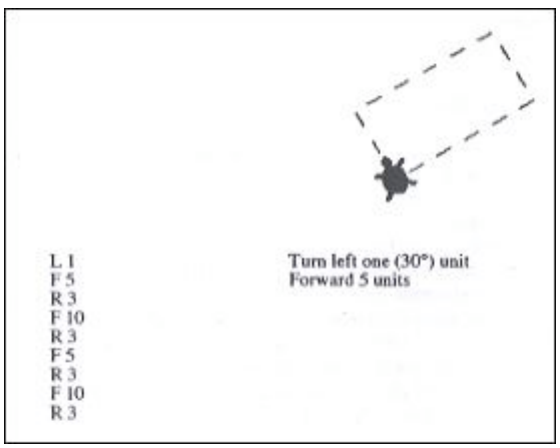

Fig. 12.2. A first grader builds up his ideas about rectangles by programming the Logo turtle to draw one that is tilted.

This boy had walked rectangular paths, drawn rectangles with pencils, and built them on geoboards and Peg-Boards. What did the computer experience add? It helped him *link* his previous experiences to more-explicit mathematical ideas. It helped him *connect* visual shapes with abstract numbers. Perhaps most important, it encouraged him to *wonder* about mathematics and pose problems in an environment in which he could create, try out, and receive feedback about his own ideas. Such discoveries happen frequently.

One preschooler, working in Logo, made the discovery that reversing the turtle's orientation and moving it backward had the same effect as merely moving it forward. The significance the child attached to this identity and his overt awareness of it was striking. Although the child had done this previously with toy cars, Logo helped him abstract a new and exciting idea for his experience (Tan 1985).

When simple turtle environments are gradually introduced, young children understand and learn from them. They transfer their knowledge to map-reading tasks and interpreting right and left rotation of objects (Clements 1983/84; Cohen and Geva 1989; Kromhout and Butzin

1993; Watson, Lange, and Brinkley 1992). Older children extend their number capabilities. Three five-year-olds determined the correct length for the bottom line of their drawing by adding the lengths of the three horizontal lines that they had constructed at the top of a tower: 20 + 30 + 20 = 70 (Clements 1983-84).

Another way of using Logo, emphasizing science, also encourages inclusion. With LEGO-Logo (Lego Dacta, Enfield, Conn), children use the Logo language to control LEGO creations, including lights, sensors, motors, gears, and pulleys. Papert (1983) observed some Boston children playing with LEGO and computers: The boys started by making trucks right away. The girls made a house. At first, the girls traded motors for things they could use to decorate their house. They were not interested in the mechanical, Logo-controlled aspects. Then, one day there was a light in one of the rooms in the house. The Logo code was simple -- "on wait 10 off wait 10." Later there were several lights, than a lighted Christmas tree turned by a motor. This was a soft transition. The girls found their own way into the full use of LEGO-Logo. With Logo, fantasy, technology, mathematics, science, and personal ways of knowing can come together in natural connections rather than remain separate, specialized subjects. One boy puts it well: "If we didn't have the computer, what could we use to say that the electricity should flow and then it should stop? Where would we put our knowledge: We can't just leave it in our heads. We know it, we think it, but our programs would stay in our heads" (Winer and Trudel 1991).

The Computer's Role in the Home and Preschool

What is happening in homes and schools? Unfortunately, most children use computers only occasionally -- and usually only when their teachers want to add variety or rewards to the curriculum. Unfortunate children use mostly drill-and-practice software, their teachers stating that their goal for using computers is to increase basic skills rather than develop problem-solving or creative skills (Becker 1990, Hickey 1993).

However, this is changing: More fortunate young children are becoming more likely to have computers in their classrooms. More early childhood teachers are choosing open-ended programs based on developmental issues (Haugland 1997). Placing computers in kindergartners' classrooms for several months significantly increases children's skills; placing them in the home yields greater gains (Hess and McGarvey 1987). However, in the home, children more often play computer games than use instructional software. This is especially unfortunate. We need additional software and programs that bridge the school-home and entertainment-learning gaps.

When children do use computers, how do they interact? Contrary to initial fears, computers do not isolate children. Rather, they serve as potential catalysts for social interaction. Children spent nine times as much time talking to peers while on the computer than while doing puzzles (Muller and Perlmutter 1985). Researchers observe that 95 percent of children's talking while using Logo is related to their work (Genishi, McCollum, and Strand 1985). Children prefer to work with a friend rather than alone, and they make new friends around the computer. There is greater and more spontaneous peer teaching and helping (Clements and Nastasi 1992).

As estimated, near the turn of the century the ratio of children to computers will be 10:1, which meets the recommended minimal ratio. In classrooms with proportionally fewer computers, aggressive behavior ma be increased (Clements and Nastasi 1993; Coley, Cradler, and Engel 1997.)

Children's interactions at the computer are affected by the software they are using. Open-ended programs like Logo foster collaborative groups characterized by patterns of goal setting, planning, negotiating, and resolving conflicts. Drill-and-practice software can encourage turn taking, but it also engenders a competitive spirit. Similarly, gamelike programs with aggressive content can engender the same qualities in children (Silvern and Williamson 1987). Games involving cooperative interaction can improve children's social behavior (Garaigordobil and Echebarria 1995). A computer simulation of a Smurf environment (Forman 1986). This may be due to features of the computer; in the computer environment, the Smurf characters could literally share the same space ad could even jump "through" one another. The forced shared space of the computer program also caused children to talk to one another more.

In addition, computers may engender in advanced cognitive type of play among children. In one study, "games with rules" was the most frequently occurring type of play among preschoolers working at computers (Hoover and Austin 1986). So already prevailing patterns of social participation and cognitive play were enhanced by the presence of computers. In a similar vein, children are more likely to get correct answers when they work cooperatively, rather than competitively, on educational computer games (Strommen 1993).

Changes in the Adults' Role

The nature of computers changes the adults' role as teacher, sometimes subtly. With careful attention to establishing physical arrangements, giving assistance, selecting software programs, and enhancing learning, adults can do much to optimize computers' advantages.

By altering the physical arrangement of the computers in the classroom, teachers can enhance their social use (Davidson and Wright 1994). Placing two seats in front of the computer and one at the side for an adult can encourage positive social interaction. Placing computers close to one another can facilitate the sharing of ideas among children. Computers that are centrally located as "learning centers" in the classroom invite other children to pause and participate in the computer activity. Such an arrangement also helps keep adults' participation at an optimum level because they are nearby to provide supervision and assistance as needed -- substantial initial guidance that tapers off -- but are not constantly so close as to inhibit the children (Clements 1991).

Adults also have to find a delicate balance in providing assistance. Teachers and parents should give "just enough" guidance, but not too much. Intervening too much or at the wrong time can decrease peer tutoring and collaboration. (Emihovich and Miller 1988). Without any adult guidance, however, children tend to jockey for position at the computer and use it in a turn-taking, competitive manner (Silvern, Countermine, and Williamson 1988). Adults' roles have to change in accordance with the changing needs of children. Initially, adults may need to be more demonstrative, assisting children with problem solving, goal setting, and planning. However, once children have gained confidence and expertise, adults can recede to being observers and facilitators, ready to help when needed (Clements and Nastasi 1992).

Even more than with print materials, adults have to review and select software materials carefully. For example, drill-and-practice software, although leading to gains in certain rote skills, has not been as effective in improving the conceptual capabilities of children (Clements and Nastasi 1993). Discovery-based software that encourages and allows ample room for exploration is more valuable in this regard. Adults must find software that challenges children to solve meaningful problems. The computer should do what textbooks and worksheets do not do well -- it should help students connect multiple representations and use animation appropriately. It should encourage multiple solution strategies.

Finally, adults must carefully enhance children's learning. Effective adults will structure and guide work with rich programs to ensure children from strong, valid mathematical and scientific ideas. They know that children work best when given open-ended projects instead of the option merely to "free explore" (Lemerise 1993). Children spend more time and actively search for diverse ways to solve designated tasks, such as fitting various sizes of shoes onto computer characters' feet (see fig. 12.3). Those who are encouraged only to "free explore" soon grow disinterested.

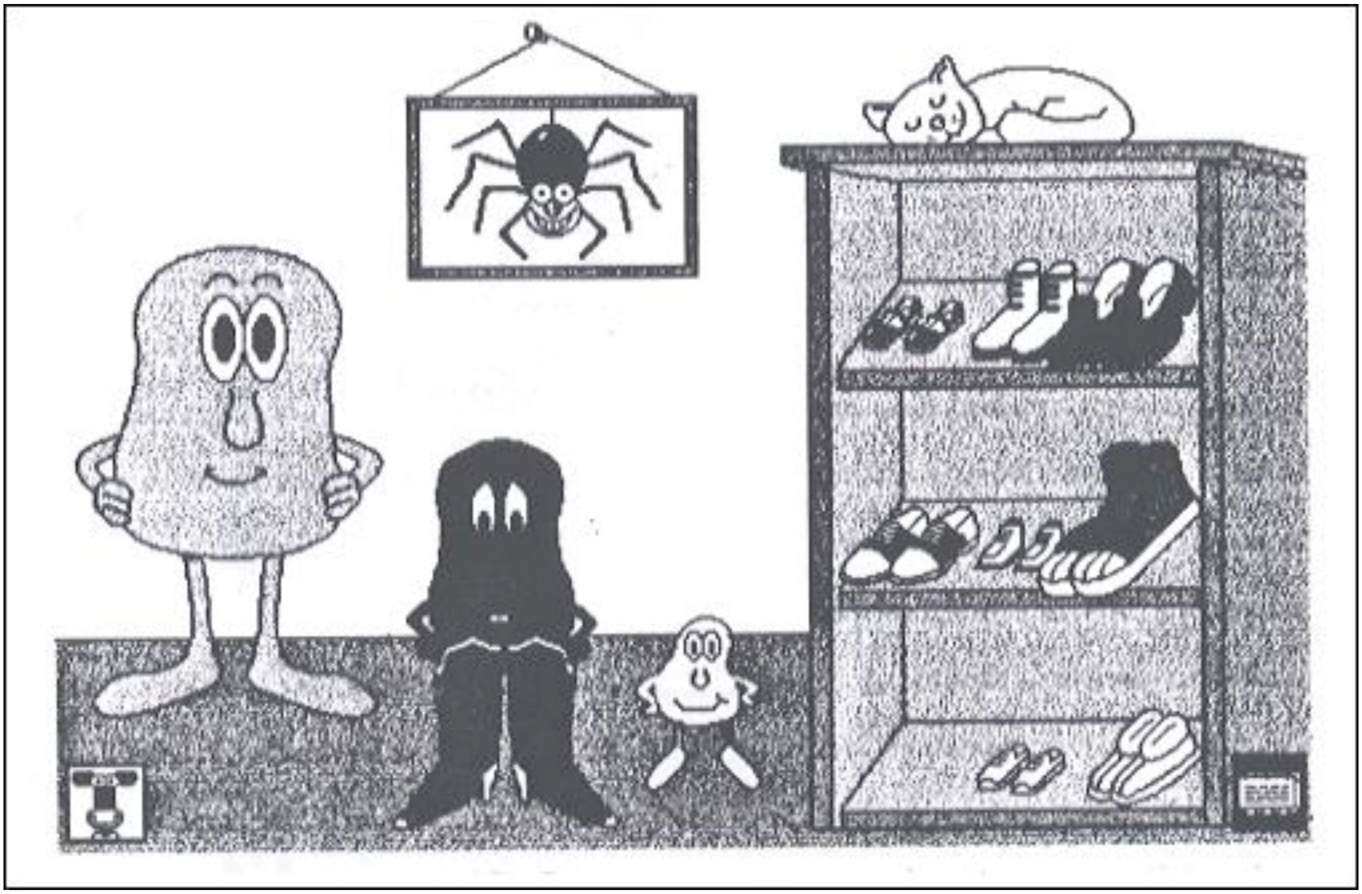

Fig. 12.3. In "Little, Middle, and Big," children match shoes to characters by size. If they click on the spider, they are given an assigned task, which delighted three-old Julie when she worked o the activity. (From Millie's Math House, published by Edmark Corp., Redmond, Wash. Reproduced with permission.)

Effective adults also raise questions about "surprises," or conflicts between children's intuitions and computer feedback, to promote reflection. They pose challenges and tasks designed to make the mathematical or scientific ideas explicit for children. They help children build bridges between the computer and other experiences. In particular, they connect computer work closely with off-computer activities. For example, preschoolers who are exposed to developmental software alone show gains in intelligence, nonverbal skills, long-term memory, mental activities, in comparison, gained in all these areas and improved their scores in verbal, problem-solving, and conceptual skills (Haugland 1992). Also, these children spent the least amount of time on computers. A control group; that used drill-and-practice software were on the computer three times as much, but showed less than half the gains that the on- and off-computer group did.

The importance of *guiding children to see and build mathematical ideas* embedded in software cannot be overemphasized. Most children experience only the surface features of rich programs without such guidance. For example, two preschoolers were trying to fill a shape they made with Kid Pix 2 (The Learning Company, Novato, Calif.) (fig. 12.4a). They were frustrated out on their own that they needed to close the shape. But it was their teacher who encouraged them to talk about their experience, describing "closed" and "not-closed" shapes using the dynamic "filling" action of the computer. Later, their teacher challenged them to figure out which of several shapes were closed (fig. 12.4c) and to find other closed and not-closed shapes in their world.

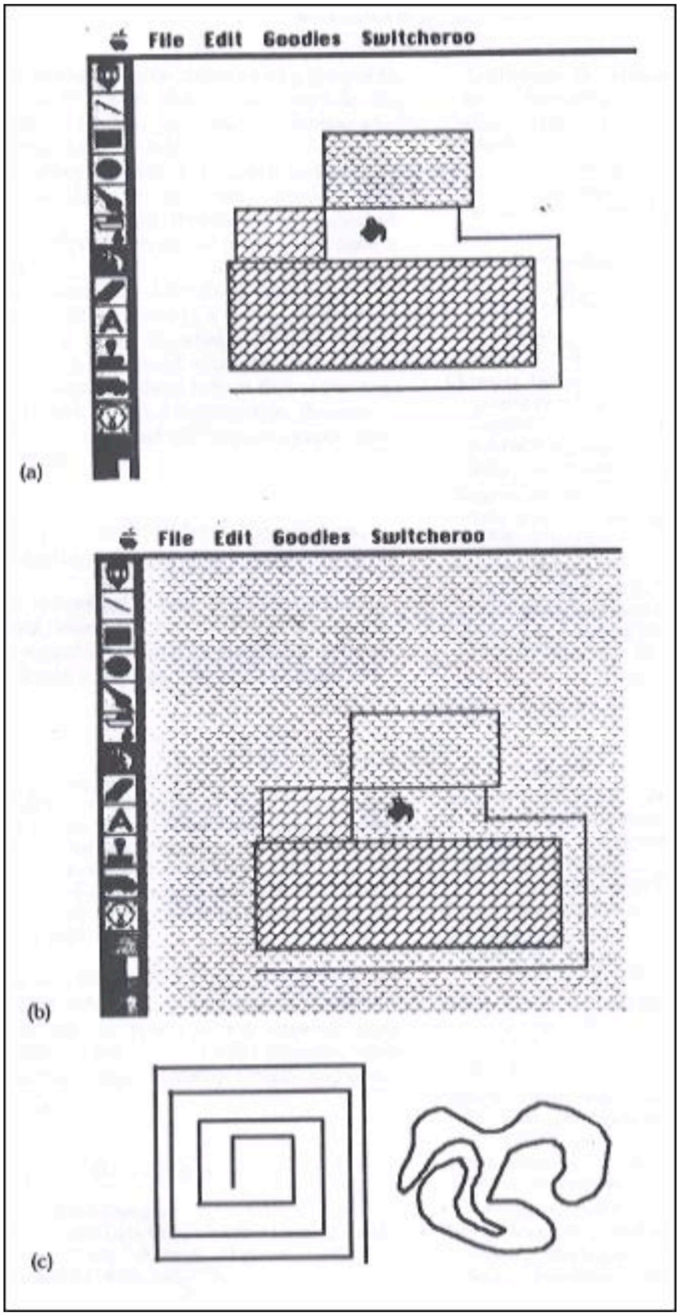

Fig. 12.4. Two girls were filling their building with colors and chose the last area (a). However to their surprise, the "paint can" filled the entire area (b). Later, the teacher made up some other closed and not-closed shapes for these children to explore wit the paint can (c). (The program is Kid Pix 2. Kid Pix is a registered trademark of The Learning Company, a division of Mattel, Inc., © 1999. All rights reserved. Used with permission.)

Effective adults allow children to use their own approaches. They take advantage of the computer's ability to engage people of different background, styles and sexes (Clements 1987; Delclos and Burns 1993). They also see the computer as a new medium for understanding children. Observing the child at the computer provides adults with a "window into a Child's thinking process" (Weir, Russell, and Valente 1982). Research has warned us, however, not to curtail observations after only a few months, that beneficial effects sometimes appear only after a year. Ongoing observations also help us chart children's growth (Cochran-Smith, Kahn, and Paris 1988).

Some effective teachers see computers as an opportunity to become pioneers of change -- making dramatic changes in their professional roles and, because they know their children best, creating imaginative computer programs. Frustrated by the lack of good software, Tom Snyder used the computer to support his classroom simulations of history. Mike Gralish, an early childhood teacher, used several computer devices and programs to link the base-ten blocks and the number system for his children. Today, both these gentlemen are leading educational innovators (Reil 1994).

To become effective computer educators and keep up with growing changes in technology, teachers need extended in-service training. Research has established that having less than ten hours of training can have a negative impact (Ryan 1993). Other research has emphasized the importance of hands-on experience and warned against brief exposure to a variety of programs rather than an in-depth knowledge of one (Wright 1994). Some early childhood educators feel anxious about using computers; others believe that technology and humanistic education are incompatible. Because of these factors, both extended and intensive experiences are recommended.

Visions of Young Children, Computers, Mathematics, and Science

One can use technology to teach the same old stuff in the same way. Integrated computer activities can increase achievement. Children who use practice software about ten minutes a day can learn simple skills. However,

if the gadgets are computers, the same old teaching becomes incredibly more expensive and biased towards its dullest parts, namely the kind of rote learning in which measurable results can be obtained by treating the children like pigeons in a Skinner box . . . I believe with Dewey, Montessori, and Piaget that children learn by doing and by thinking about what they do. And so the fundamental ingredients of educational innovation must be better things to do and better way to think about oneself doing these things. (Paper 1980, p. 161)

We believe, with Papert, that computers can be a rich source of these ingredients. We believe that having young children use computers in new ways -- to pose and solve problems, draw, and do turtle geometry -- can help them learn and develop mathematically and scientifically.

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