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ABSTRACT

Research on the use of computers and other educational technology with young children has become increasingly sophisticated as their use has increased in early childhood educational settings. This paper reviews the research on computers and social interaction, teaching with computers, and curriculum and computers. The review finds that computers serve as catalysts for social interaction, with children spending nine times as much time talking with peers while working at computers than while doing puzzles. Social interactions are influenced by the type of software used and the physical environment surrounding the computer. Computers and other technology offer opportunities to aid learning through making more visible individual and gender differences in approaches to learning. Effectively integrating technology into the early childhood curriculum entails several issues, including matching the type of computer software used with the skills desired and coupling computer and off-computer activities for maximum learning. The paper then describes The Building Blocks curriculum for pre-kindergarten through grade 2; this technology-based curriculum is designed to enable young children to build mathematics knowledge and develop higher-order thinking skills. The curriculum integrates computers, manipulatives, and print materials. (Contains 36 references.) (KB)

YOUNG CHILDREN AND TECHNOLOGY

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YOUNG CHILDREN AND TECHNOLOGY

Douglas Clements

Computers are increasingly present in early childhood education settings. Toward the end of the 1980s, only a fourth of licensed preschools had computers. Today almost every preschool has a computer, with the ratio of computers to students changing from 1:125 in 1984 to 1:22 in 1990 to 1:10 1997. This matches the minimum ratio favorable to social interaction (Clements & Nastasi, 1993; Coley, Cradler, & Engel, 1997). During the same period, perspectives on the principle of developmental appropriateness have become more sophisticated. Researchers have extended them to include such dimensions as cultural paradigms and multiple intelligences (Bowman & Beyer, 1994; Spodek & Brown, 1993).

Research on young children and technology similarly has moved beyond simple questions to consider the implications of these changing perspectives for the use of technology in early childhood education. For example, we no longer need to ask whether the use of technology is "developmentally appropriate." Very young children have shown comfort and confidence in using software. They can follow pictorial directions and use situational and visual cues to understand and think about their activity (Clements & Nastasi, 1993). Typing on the keyboard does not seem to cause them any trouble; if anything, it is a source of pride.

With the increasing availability of hardware and software adaptations, children with physical and emotional disabilities also can use the computer with ease. Besides enhancing their mobility and sense of control, computers can help improve their self-esteem. One totally mute four-year-old with diagnoses of retardation and autism began to echo words for the first time while working at a computer (Schery & O'Connor, 1992). However, such access is not always equitable across our society. For example, children attending low-income and high-minority schools have less access to most types of technology (Coley et al., 1997)

Research has also moved beyond the simple question of whether computers can help young children learn. It can. What we need to understand is how best to aid learning, what types of learning we should facilitate, and how to serve the needs of diverse populations. In some innovative projects, computers are more than tools for bringing efficiency to traditional approaches. Instead, they open new and unforeseen avenues for learning. They allow children to interact with vast amounts of information from within their classrooms and homes. And they tie children from across the world together (Riel, 1994).

This does not mean that every use of technology is appropriate or beneficial. The design of the curriculum and social setting are critical. This article continues reviewing the research in three broad areas: social interaction, teaching with computers, and curriculum and computers. Finally, it describes a new project that illustrates innovative technology-based curriculum for early childhood education.

SOCIAL INTERACTION

An early concern, that computers will isolate children, was alleviated by research. In contrast, computers serve as *catalysts* for social interaction. The findings are wide-ranging and impressive. Children at the computer spent nine times as much time talking to peers while on the computer than while doing puzzles (Muller & Perlmutter, 1985). Researchers observe that 95 percent of children's talking during Logo work is related to their work (Genishi, McCollum, & Strand, 1985). (Logo is a computer programming language designed to promote learning. Even young children can use it to direct the movements of an on-screen "turtle.") Children prefer to work with a friend rather than alone. They foster new friendships in the computer's presence. There is greater and more spontaneous peer teaching and helping (Clements & Nastasi, 1992).

The software they use affects children's social interactions. For example, open-ended programs like Logo foster collaboration. Drill and practice software, on the other hand, can encourage turn taking but also competition. Similarly, video-games with aggressive content can engender competitiveness and aggression in children. Used differently, however, computers can have the opposite effect (Clements & Natasi, 1992). In one study, a computer simulation of a Smurf playhouse attenuated the themes of territoriality and aggression that emerged with a real playhouse version of the Smurf environment (Forman, 1986).

The physical environment also affects children's interactions (Davidson & Wright, 1994). Placing two seats in front of the computer and one at the side for the teacher can encourage positive social interaction. Placing computers close to each other can facilitate the sharing of ideas among children. Centrally located computers invite other children to pause and participate in the computer activity. Such an arrangement also helps to keep teacher participation at an optimum level. Teachers are nearby to provide supervision and assistance as needed, but are not constantly so close as to inhibit the children (Clements, 1991).

TEACHING WITH COMPUTERS

The computer offers unique advantages in teaching. Opportunities to aid learning are addressed in the following section. Technology also offers unique ways to assess children. Observing the child at the computer provides teachers with a "window into a child's thinking process" (Weir, Russell, & Valente, 1982). Research has also warned us not to curtail observations after a few months. Sometimes beneficial effects appear only after a year. On-going observations also help us chart children's growth (Cochran-Smith, Kahn, & Paris, 1988).

Differences in learning styles are more readily visible at the computer where children have the freedom to follow diverse paths towards the goal (Wright, 1994). This is particularly valuable with special children, as the computer seems to reveal their hidden strengths. Different advantages emerge for other groups of children. For example, researchers have found differences in Logo programming between African-American and Caucasian children. The visual nature of Logo purportedly was suited to the African-American children's thinking style (Emihovich & Miller, 1988).

Gender differences also emerge while programming. In one study, a post-test only assessment seemed to indicate that boys performed better. However, assessment of the children's interactions revealed that the boys took greater risks and thereby reached the goal. In comparison, girls were more keen on accuracy and hence meticulously planned and reflected on every step (Yelland, 1994). Again, the implication for teaching is consistent, long-term observation.

Yet another opportunity offered us by technology is to become pioneers ourselves. Because we know our children best, we can best create the program that will help them. Frustrated by the lack of good software, Tom Snyder started using the computer to support his classroom simulations of history. Mike Gralish, a first-grade teacher, used several computer devices and programs to link the base-10 blocks and the number system for his children. Today, both of these gentlemen are leading educational innovators (Riel, 1994).

To accomplish this and to keep up with the growing changes in technology, teachers need in-service training. Research has established that less than ten hours of training can have a negative impact (Ryan, 1993). Others have emphasized the importance of hands-on experience and warned against brief exposure to a variety of programs, encouraging an in-depth knowledge of one (Wright, 1994).

CURRICULUM AND COMPUTERS

The computer also offers unique opportunities for learning through exploration, creative problem solving, and self-guided instruction. Realizing this potential demands a simultaneous focus on curriculum and technology innovations (Hohmann, 1994). Effectively integrating technology into the curriculum demands effort, time, commitment, and sometimes even a change in one's beliefs.

We begin with several overarching issues. What type of computer software should be used? Drill and practice software leads to gains in certain rote skills. However, it has not been as effective in improving the conceptual skills of children (Clements & Nastasi, 1993). Discovery-based software that encourages and allows ample room for free exploration is more valuable in this regard. However, in designing curriculum around this software, research has shown that children work best when designated open-ended projects rather than asked merely to "free explore" (Lemerise, 1993). They spend more time and actively search for diverse ways to solve the task. The group allowed to free explore grew disinterested quite soon.

An early fear was that computers would replace other early childhood activities. Research shows that computer activities yield the best results when coupled with suitable off-computer activities. For example, children who are exposed to developmental software alone show gains in intelligence, non-verbal skills, long-term memory, and manual dexterity. Those who also work with supplemental activities, in comparison, gained in all of 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 spent three times as long on the computer but showed less than half of the gains that the on- and off- computer group did. Given these capabilities of the computer, how has it affected children's learning?

In mathematics specifically, the computer can provide practice on arithmetic processes and foster deeper conceptual thinking. Drill and practice software can help young children develop competence in counting and sorting (Clements & Nastasi, 1993). However, it is questionable if the exclusive use of such drill software would subscribe to the vision of the National Council of Teachers of Mathematics (NCTM) (1989) to be "mathematically literate" in a world where "mathematics is rapidly growing and is extensively being applied in diverse fields." NCTM recommends that we "create a coherent vision of what it means to be 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" (National Council of Teachers of Mathematics, 1989). This vision *de*-emphasizes rote practice on isolated facts. It emphasizes discussing and solving problems in geometry, number sense, and patterns with the help of manipulatives and computers.

For example, using programs that allow the creation of pictures with geometric shapes, children have demonstrated growing knowledge and competence in working with concepts such as symmetry, patterns and spatial order. Tammy overlaid two overlapping triangles on one square and colored select parts of this figure to create a third triangle that did not exist in the program! Not only did this preschooler exhibit an awareness of how she had made this, but she also showed 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 out of reach of young children. The computer experience led the children to explorations that expanded their boundaries.

Young children can also explore simple "turtle geometry." They direct the movements of a robot or screen "turtle" to draw different shapes. One group of five-year-olds was constructing rectangles. "I wonder if I can tilt one," mused one boy. He turned the turtle with a simple mathematical command, "L 1" (turn left one unit), drew the first side, then was unsure about how much to turn at this strange new heading. He finally 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. 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 & Battista, 1992). This boy had walked rectangular paths, drawn rectangles with pencils, and built them on geo-boards and pegboards. 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 made the discovery that reversing the turtle's orientation and moving it backwards had the same effect as merely moving it forwards. Striking was the significance the child attached to this identity and his overt awareness of it. Though the child had done this previously with toy cars, Logo helped him abstract a new and exciting idea for his experience (Tan, 1985).

BUILDING BLOCKS©: AN INNOVATIVE TECHNOLOGY-BASED CURRICULUM

Julie Sarama and I are presently working to develop innovative pre-k to grade 2 curriculum materials. The project, "Building Blocks—Foundations for Mathematical Thinking, Pre-Kindergarten to Grade 2: Research-based Materials Development,"[1] is designed to enable all young children to build solid content knowledge and develop higher-order thinking. The design is based on current theory and research to represent a state-of-the-art technology curriculum for young children in the area of mathematics. We discuss it in that light. The reader might notice that our description does not begin with a listing of technologically sophisticated issues, including multimedia features. This is because we emphasize the art and science of teaching and learning, rather than too much early childhood software—technologically advanced bells and whistles disguising ordinary activities.

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Design of a state-of-the-art curriculum must begin with audience considerations. The demographics of this age range imply that materials should be designed for home, daycare, and classroom environments and for children from a variety of backgrounds, interests, and ability levels. To reach this broad spectrum, the materials will be progressively layered—users will be able to "dig deeper" into them to reach increasingly rich, but demanding, pedagogical and mathematical levels. The materials should not rely on technology alone, but should integrate three types of media: computers, manipulatives (and everyday objects), and print. Here we will focus on the computer materials.

Our basic educational approach is finding the mathematics in and developing mathematics from children's activity. We wish to help children extend and find mathematics in their everyday activities, from building blocks to art to songs to puzzles. Thus, we will design activities based on children's experiences and interests, with an emphasis on supporting the development of mathematical activity. This process emphasizes representation: using mathematical objects and actions that relate to children's everyday activities. Our materials will embody these actions-on-objects in a way that mirrors the theory of and research on children's *cognitive building blocks*—creating, copying, uniting, and dis-embedding both units and composite units.

Perhaps the most important aspect of our material design is our model for the design process. Curriculum and software design can and should have an explicit theoretical and empirical foundation, beyond its genesis in someone's intuitive grasp of children's learning. It also should interact with the ongoing development of theory and research—reaching toward the ideal of testing a theory by testing the software and the curriculum in which it is embedded. In this model, one conducts research at multiple aggregate levels, making the research relevant to educators in many positions. We have cognitive models with sufficient explanatory power to permit design to grow co-jointly with the refinement of these cognitive models (Biddlecomb, 1994; Clements & Sarama, 1995; Fuson, 1992; Hennessy, 1995). Phases of our nine-step design process model include: draft curriculum goals, build an explicit model of children's knowledge and learning in the goal domain, create an initial design, investigate components, assess prototypes and curriculum, conduct pilot tests, conduct field tests in multiple settings, recurse, and publish and disseminate. These phases include a close interaction between materials development and a variety of research methodologies, from clinical interviews to teaching experiments to ethnographic participant observation.

Reflective consideration of objects, actions, and activities that a new technology enables can help developers re-conceptualize the nature and content of mathematics that might be learned. The developer can also focus designs by reflecting on how software might provide tools that enhance students' actions and imagination or that suggest an encapsulation of a process or obstacles that force students to grapple with an important idea or issue. Finally, the flexibility of computer technologies allows the creation of a vision less hampered by the limitations of traditional materials and pedagogical approaches (cf. Confrey, in press). For example, computer-based communication can extend the model for mathematical learning beyond the classroom and computers can allow representations and actions not possible with other media. The *Building Blocks* materials will not only ensure that computerized actions-on-objects mirror the goal concepts and procedures, but also that they are embedded in tasks and developmentally appropriate settings (e.g., narratives, fantasy worlds, building projects).

The materials will emphasize the development of basic *mathematical building blocks*—ways of knowing the world mathematically—organized into two areas: (a) spatial and geometric competencies and concepts and (b) numeric and quantitative concepts, based on the considerable research in that domain. Three mathematical sub-themes: (a) patterns & functions, (b) data, and (c) discrete mathematics (e.g. classifying, sorting, sequencing) will be woven through both main areas. Most important will be the synthesis of these domains, each to the benefit of the other. The building blocks of the structure are not elementary school topics "pushed down" to younger ages, but developmentally appropriate domains (i.e., meaningful and interesting to children. However, this does not mean restricting access to such topics as large numbers or geometric ideas such as depth, which research indicates are both interesting and accessible to young children).

By presenting concrete ideas in a symbolic medium, for example, the computer can help bridge these two concepts for young children. But are these manipulatives still "concrete" on the computer screen? One has to examine what "concrete" means. Sensory characteristics do not adequately define it (Clements & McMillen, 1996; Wilensky, 1991). First, it cannot be assumed that children's conceptions of the manipulatives are similar to adults' (Clements & McMillen, 1996). Second, physical actions with certain manipulatives may suggest different mental actions than those we wish students to learn. For example, researchers found a mismatch among students using the number line to perform addition. When adding five and four, the students located 5, counted "one, two, three, four," and read the answer. This did not help them solve the problem mentally, for to do so they have to count "six, seven, eight, nine" and at the same time count the counts— 6 is 1, 7 is 2, and so on. These actions are quite different (Gravemeijer, 1991).

Thus, manipulatives do not always carry the meaning of the mathematical idea. Students must use these manipulatives in the context of well-planned activities and ultimately reflect on their actions to grasp the idea. Later, we expect them to have a "concrete" understanding that goes beyond these physical manipulatives.

It appears that there are different ways to define "concrete" (Clements & McMillen, 1996). We define sensory-concrete knowledge as that in which students must use sensory material to make sense of an idea. For example, at early stages, children cannot count, add, or subtract meaningfully unless they have actual objects to aid in those functions. They build integrated-concrete knowledge as they learn. Such knowledge is connected in special ways. This is the root of the word concrete: "to grow together." What gives sidewalk concrete its strength is the combination of separate particles in an interconnected mass. What gives integrated-concrete thinking its strength is the combination of many separate ideas in an interconnected structure of knowledge (Clements & McMillen, 1996).

For example, computer programs may allow children to manipulate on-screen "building blocks." These blocks are not physically concrete. However, no base-10 blocks "contain" place value ideas (Kamii, 1986). Students must build these ideas from working with the blocks and thinking about their actions. Further, research indicates that physical base-10 blocks can be so clumsy and the manipulations so disconnected from each other that students see only the trees (manipulations of many pieces) and miss the forest (place value ideas). The computer blocks can be more manageable and "clean" (Thompson & Thompson, 1990). Students can break computer base-10 blocks into ones, or glue ones together to form tens. These actions are more in line with the mental actions that we want students to learn—these are children's cognitive building blocks.

One essential cognitive "building block" of place value is children's ability to count by ten from any number—constructing composite units of ten (Steffe, 1997). The computer helps students to make sense of their activity and the numbers by linking the blocks to symbols. For example, the number represented by the base-10 blocks is usually dynamically linked to the students' actions with the blocks, automatically changing the number spoken and displayed when the student changes the blocks. As a simple example, a child who has sixteen single blocks might glue ten together and then repeatedly duplicate this "ten." In counting along with the computer "26, 36, 46," and so on, the child constructs composite units of ten. (This example also illustrates how critical cognitive building blocks are in constructing what adults consider to be a "standard" mathematical idea.)

Computers encourage students to make their knowledge explicit, which helps them build integrated-concrete knowledge. Specific theoretically and empirically grounded advantages of using computer manipulatives include (Clements & McMillen, 1996):

- providing a manageable, clean manipulative;
- offering flexibility;
- changing arrangement or representation;
- storing, and later retrieving, configurations;
- recording and replaying students' actions;
- linking the concrete and the symbolic with feedback;
- dynamically linking multiple representations;
- changing the very nature of the manipulative;
- linking the specific to the general;
- encouraging problem posing and conjecturing;
- scaffolding problem solving; focusing attention and increasing motivation; and
- encouraging and facilitating complete, precise, explanations.

Of course, multimedia and other computer capabilities should, and will, be used when they serve educational purposes. Features such as animation, music, surprise elements, and especially consistent interaction get and hold children's interest (Escobedo & Evans, 1997). They can also aid learning, *if* they are designed to support and be consistent with the pedagogical goals. In addition, access to technology is an important equity issue. We will make much of our material available on the Internet.

In summary, we designed the *Building Blocks* project to combine the art and science of teaching and learning with the science of technology, with the latter serving the former. Such synthesis of (a) curriculum and technology development as a scientific enterprise and (b) mathematics education research will reduce the separation of research and practice in mathematics and technology education. This will produce materials based on research and research based on effective and ecologically sound learning situations. Moreover, these results will be immediately applicable by practitioners (parents, teachers, and teacher educators), administrators and policy makers, and curriculum and software developers.

FINAL WORDS

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 per day increase their scores on achievement tests. 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 ways to think about oneself doing these things. (Papert, 1980).

We believe, with Papert, that computers can be a rich source of these ingredients. We believe that having children use computers in new ways—to solve problems, manipulate mathematical objects, create, draw, and write simple computer programs—can be a catalyst for positive school change.

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