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Strip Mining for Gold: Research and Policy in Educational Technology—A Response to "Fool's Gold"

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Several recent articles have addressed the issue of the translation and interpretation of education research for the purpose of affecting policy (e.g., Educational Researcher 29(6).) We respond to the publication of, and media attention to, "Fool's gold: A critical look at computers in childhood" (Cordes & Miller, 2000). This report delineates some important issues for discussion and includes several valid concerns. However, we believe it's presentation of half-truths and misleading interpretations of theory and research under the guise of academic respectability not only presents an unfortunate one-sided picture of the issues and related empirical research, but, more generally, plays the U.S. media game to the detriment of research, intellectual discourse, and, ultimately, children. Misuse of technology by some and overzealous promotion by others are not valid reasons for misrepresenting the field or for speciously framing the computer as the lightning rod for a broad range of criticisms that we argue can be reasonably attributed to no single source. Such incomplete and dishonest reporting misdirects attention from the wider web of political and pedagogical concerns, trammels the progress of research and expert practice that can guide developmentally appropriate and beneficial use of computers, and does violence to the academic enterprise by reinforcing the cynical belief that research can also support either of polar opposite opinions. In this article, we hope to correct misconceptions about computers in education, but more so, to argue for a complete, balanced, consideration and reporting of research, especially when addressing policy implications.

In 1995, we argued that "we no longer need to ask whether the use of technology is 'appropriate'" in early childhood education (Clements & Swaminathan, 1995). The research supporting that statement was, and remains, convincing, but social and political movements follow their own cyclic course. The most recent example is the publication of *Fool's gold: A critical look at computers in childhood* (Cordes & Miller, 2000). This report delineates some important issues for discussion and includes several valid concerns. However, we believe that it may do more harm than good because it's presentation of half-truths and misleading interpretations of theory and research under the guise of academic respectability not only presents an unfortunate one-sided picture of the issues, but, more generally, plays the U.S. media game to the detriment of research, intellectual discourse, and, ultimately, children.

In this response, we will not address all of the lacunae and misrepresentations in the report, as this would require an extensive revisiting of research already available in several sources (Behrmann, 2000; Clements & Nastasi, 1992; Clements & Sarama, 1997). Instead, we address several major problems with this particular report and, using it as a case, draw implications for reports in this genre. The major sections deal with research on young children and computers; following these sections, we discuss areas of agreement and the issue of full reporting of research results, and end with conclusions and implications.

COMPUTERS, CHILDREN, AND RESEARCH

Fool's gold argues that computers pose serious hazards to children, physically, emotionally, intellectually, and developmentally. It describes children's need for exercise, direct experience with the natural world, and strong personal bonds with caring adults, implying a mutual exclusivity between meeting these needs and using computers. The report explicitly states that these and other arguments are based on research. However, the research reported is often of a general nature, with vague textual contiguities and non sequiturs substituting for bona fide implications.

Fool's gold quotes Larry Cuban as saying that there "is no clear, commanding body of evidence that students' sustained use of multimedia machines, the Internet, word processing, spreadsheets, and other popular applications has any impact on academic achievement" (p. 3). Undoubtedly, anyone

attempting to craft a polemic can argue that the body of evidence on almost any educational domain is not sufficiently clear or commanding. Nevertheless, this statement can only be valid if it is addressing what is typically done with computers (which is not what the quote or the report in general implies), otherwise, it ignores a considerable research corpus. Cuban (2001) himself has stated that the literature is "filled with studies that demonstrate more students learning through using computers than conventional means of instruction" (p. 204). It is equally disappointing that most of the empirical work on educational use of computers with young children is not reviewed or discussed in the report.

The body of research that *Fool's gold* ignores is substantive. Consider research on early childhood (birth to grade 3), arguably the most contentious level for computer use. Not only are there hundreds of studies in the literature, but there are useful reviews summarizing this research. Indeed, many of these reviews—published before the Alliance even began their report—pose the same issues and bring research evidence to bear on them specifically (Clements & Nastasi, 1992; Fatouros, 1995; Watson, Nida, & Shade, 1986). These reviews do not commit the egregious error of lumping every possible use of computer technology into one category, as does *Fool's gold*. Rather, they differentiated various uses of computers, including non-educational game use, drill and practice, and programs providing unique, rich, educational experiences; they further discussed the advantages and disadvantages of each (Behrmann, 2000; Clements & Nastasi, 1992; Fatouros, 1995; Ishigaki, Chiba, & Matsuda, 1996; Watson et al., 1986).

Thus, *Fool's gold* contains critical flaws. *Fool's gold* never clarifies what question it is asking. Is it "Do computers as such do X or have effect Y"? This lumping all computer uses together is a form of what Papert years ago called "technocentrism" (Papert, 1985)[2]; such questions are simplistic to the degree that they are not educationally useful. Or, is *Fool's gold's* question, "What are the average effects of computers as they are generally used in schools today?" The report's failure to clarify the questions and its lack of differentiation among various uses of computers are critical methodological flaws. Just as serious is *Fool's gold's* selective reporting, and especially its reckless disregard, of the extant research.

In light of both the report's methodological errors and the existence of a substantive research corpus, the issues raised by *Fool's gold* look quite different indeed, reflecting badly on the authors and those who signed the

report. We illustrate our arguments by focusing on key issues regarding computer use in early childhood education, including social and emotional development, cognitive development and learning, and the broad issues of the use of computers and children's development.[3]

SOCIAL AND EMOTIONAL DEVELOPMENT

Fool's gold is unabashedly critical of every aspect of technology. One of the main concerns is the ill effect on social and emotional development. "Children need stronger personal bonds with caring adults. Yet powerful technologies are distracting children and adults from each other" (p. 3). No evidence that such distraction is present or substantial is provided. Instead, confusing children's use of computers in classrooms with Dilbert-like adult use of computers in cubicles, the report conjures a vision of technologically-driven social isolation.

Research on the educational use of computers paints a different picture. Contrary to critics' fears, for example, educational computer programs do not isolate children. Just the opposite—computers can serve as catalysts for positive social interaction. As one example, children at the computer spent nine times as much time talking to peers while on the computer than while doing puzzles (Muller & Perlmutter, 1985). Other research shows that the nature of their interaction tends to be positive.

Children Working at the Computer

Children overwhelmingly display positive emotions when using computers (Ishigaki et al., 1996; Shade, 1994). They show higher positive affect and interest when they use the computer together (Shade, 1994) and prefer to work with a peer rather than alone[4] (Lipinski, Nida, Shade, & Watson, 1986; Rosengren, Gross, Abrams, & Perlmutter, 1985; Swigger & Swigger, 1984). Further, working on the computer can instigate new instances and forms of collaborative work such as helping or instructing, and discussing and building upon each others' ideas (Clements, 1994). In one study, computers added a new dimension of participation, dyadic peer interaction, in which children developed a different sense of social relations, assisting each other

and cooperating to solve problems and complete tasks. These interactions enhanced their learning and understanding; in explaining topics to peers, children restructured their own understanding (Mehan, 1989).

The addition of a computer center does not disrupt ongoing play, but rather facilitates extensive positive social interaction, cooperation, and helping behaviors (Binder & Ledger, 1985; King & Alloway, 1992; Rhee & Chavnagri, 1991; Rosengren et al., 1985). Even in the preschool classroom, a computer center fosters a positive climate characterized by praise and encouragement of peers (Klinzing & Hall, 1985). Computer activity was more effective in stimulating vocalization than toys in a regular preschool environment and also evoked higher levels of social play (McCormick, 1987).

Four- and five-year-olds from an urban, economically disadvantaged population asked others to join in, sought help from each other, and sought approval or acknowledgement from the teacher as they worked with computers (Bowman, 1985). One teacher-researcher stated that her independent, egocentric children learned cooperation and problem-solving with their peers at the computer. Their cooperative play at the computer paralleled the proportion of cooperative play in the block center (Anderson, 2000). Further, cooperation in a computer center sometimes provides a context for initiating and sustaining interaction that can be transferred to play in other areas as well, especially for boys.

Other studies have similar findings. New friendships have been fostered in the computer's presence. There is greater and more spontaneous peer teaching and helping (Clements & Nastasi, 1992; King & Alloway, 1992). Also encouraging is the finding that preschooler's participation in computer activities facilitates social interaction between children with disabilities and their normally developing peers (Spiegel-McGill, Zippiroli, & Mistrett, 1989). A large-scale, multi-year study showed conclusively from every data source—interviews, observational data, and scores on a developmental measure—that every one of the study's 44 3- to 5-year old, special-needs children gained substantially and significantly in social-emotional development from their work with computers. The quantitative measure of development showed that, upon joining the program, children were making an average gain of less than half a month per month in social-emotional development. While participating in the program, children were making an average rate of progress of 1.93 months per month (Hutinger & Johanson, 2000).

The nature of children's interactions appears to follow a developmental trend, which has implications for the social use of computers with children of different ages. Initially, their social exchange consists of an egocentric focus on turn taking. Gradually, they become more peer-oriented, offering to help and to teach and finally, they are able to work collaboratively even without adult intervention (Bergin, Ford, & Meyer-Gaub, 1986; Clements, 1993; Clements & Nastasi, 1992; Emihovich & Miller, 1988; Shade, Nida, Lipinski, & Watson, 1986). Interestingly, this trend emerges both across age levels (i.e., comparing 4- to 6-year-olds in a cross-sectional design) and with greater experience in computer environments (i.e., longitudinally). Thus, it is not surprising that preschoolers may find it difficult to take the perspective of their partner and they may also have trouble balancing the cognitive demands of problem-solving tasks simultaneously with managing the social relations (Perlmutter, Behrend, Kuo, & Muller, 1986). Such developmental limitations do not necessarily have to preclude some types of cooperative work for the very young. Children as young as 4 years of age can provide help through verbal instruction and demonstration. They often emulate their teacher's behavior when teaching their peers; therefore, teachers should take extra care to think about their instructional strategies. As an interesting note, preschool children were effective tutors of anxious adults, so much so that their strategies were effective even when used by other adults (Doran & Kalinowski, 1991)! However, developmental limitations may suggest that most children must be 5 years or more to benefit from or solve difficult problems collaboratively.

Thus, children are not harmed by appropriate computer use. Moreover, with suitable tasks and settings (e.g., use of the computer as a learning center, and awareness of the types of cooperation children benefit from at various ages), all young children can benefit socially and emotionally.

Different Types of Software

As we stated, it is essential not to treat all computer software similarly (i.e., to avoid technocentrism).[4] For example, open-ended programs such as Logo foster collaboration characterized by patterns of goal-setting, planning, negotiation, and resolution of conflicts. Logo has been shown to increase preschoolers' self-efficacy and internal locus of control (Bernhard & Siegel, 1994). Interactive literacy programs may increase young students' use of

computers, enhance computer skills, computer self-efficacy, and enjoyment of computers (Ross, Hogaboam-Gray, & Hannay, 2001). Drill and practice software, on the other hand, can encourage turn-taking but also engender a competitive spirit (Clements & Nastasi, 1992).

Concerns such as those about violence in computer games should be considered and addressed; however, lumping arcade games and educationally rich activities together, as does *Fool's gold*, is unconscionable (Ishigaki et al., 1996)[5]. This is a major and recurring error in the report: Drill and practice software, creativity tools, violent computer games, even commercial television, are often lumped together in one category. What person so categorizes textbooks, pulp fiction or bad children's series, religious works, racist propaganda, and great novels (much less money)—just because they are printed on paper? Similar to different uses of paper, different uses of computers must be considered separately (this is why, when we write implications for teachers, we are just as often critical of some computer uses as we are cautiously optimistic about others). The type of software they are using affects children's interactions at the computer. Let us consider just a few more examples. Violence in videogames, as violence in any medium, can engender the same qualities in young (Clements & Nastasi, 1992; Subrahmanyam, Kraut, Greenfield, & Gross, 2000), although even in this domain there are some exceptions (that such games may sometimes, consistent with psychoanalytic theory, discharge aggressive impulses, Graybill, Kirsch, & Esselman, 1985). However, the same game presented through a computer simulation has engendered less anti-social behaviors (Clements & Nastasi, 1992). In contrast, games specifically designed to involve cooperative interaction and symbolic play can stimulate significant improvement in social behavior (Garaigordobil & Echebarria, 1995). Similarly, other computer environments may facilitate the development of prosocial behaviors. 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, 1985, 1986). This may be due to features of the computer; in the computer environment, the Smurf characters could literally share the same space and could even jump "through" one another. The "forced" shared space of the computer program also caused children to talk to each other more. Finally, a mixture of software has been used successfully as a play therapy tool for preschoolers (Kokish, 1994).

In summary, the early childhood computer activity center functions positively as a social center (Fatouros, 1995); choosing the right type of software to meet the right goal is an important task for adults, because effects do differ

depending on the type of software used. Universally condemning "computers" for their effect on children's social and emotional environment, however, is inaccurate and potentially harmful. First, it denies the many positive uses that research has identified, such as that briefly described here. Second, it offers avoidance of all technology as the only viable option instead of indicating that the type and content of technology is critical.[6] We end this section with one more research finding that supports this position.

Motivation

"Computers are invariably said to be highly motivating to students. But those who make this assertion rarely provide specific evidence for their claim. They rarely attempt to quantify the presumed increase in motivation…" (p. 30). Anything more than a surface review of this literature would constitute an article in itself; we can assuredly document that specific evidence for the potential of computers to motivate academic work abounds (Bergin, Ford, & Hess, 1993; Blanton, Moorman, Hayes, & Warner, 2000; Bradley, 1982; Chang & Osguthorpe, 1990; Cognition and Technology Group at Vanderbilt, 1998; Elliott, 1993; Fisher, 1990/91; Gore, Morrison, Maas, & Anderson, 1989; Howland, Laffey, & Espinosa, 1997; Kelly & O'Kelly, 1994; Kurth, 1987; Malone, 1980; Matthew, 1997; Nastasi & Clements, 1993, 1994; Nastasi, Clements, & Battista, 1990; Neufeld, 1989; Okolo, 1991; Terrell & Rendulic, 1996; Try, 1989; Villarruel, 1990; Watson, Cox, & Johnson, 1993). Furthermore, although many researchers would not believe that all results could and should be quantified; controlled, quantitative evidence exists in this literature.

The Synergy of Social and Cognitive Interactions

Computers appear to facilitate both social and cognitive interactions. Researchers have observed that 95% of children's talking during Logo is related to their work (Genishi, McCollum, & Strand, 1985). Further, computers produce a more advanced cognitive type of play than other centers (Hoover & Austin, 1986). In one study, the computer was the only activity that resulted in high levels of both language development and cooperative play (Muhlstein & Croft, 1986). Finally, working with Logo has been found

simultaneously to increase both prosocial and higher–order thinking behaviors (Clements, 1986; Clements & Nastasi, 1985). Thus, computers may represent an environment in which both cognitive and social interactions simultaneously are encouraged, each to the benefit of the other. As we shall see, research on the cognitive influences of computer use support this claim.

COGNITIVE DEVELOPMENT AND LEARNING

Recall that *Fool's gold* was quite specific in stating that "30 years of research on educational technology has produced just one clear link between computers and children's learning." "Other than that," according to the Cuban quote, "there is no clear, commanding body of evidence that students' sustained use of multimedia machines, the Internet, word processing, spreadsheets, and other popular applications has any impact on academic achievement" (p. 3). Given the precious few "clear, commanding bod[ies] of evidence" on most educational issues, such a statement merely sets up a straw man that can be easily refuted. For example, we can probably all agree that materials in every medium can be poorly made and tragically misused. Paper, too, is wasted on inappropriate drill and practice with weak content. It is probably not an overstatement to say that if we put a moratorium on all elements of education that have been misused, children would arrive at school to find an empty lot and empty classrooms. We need to look beyond simple platitudes of misuse and investigate what potential each medium affords. In this section, we examine several claims *Fool's gold* makes regarding computers and cognitive development and learning, and we compare these claims to the relevant empirical research. Here, again, we find evidence that thoughtful use of technology can aid learning. Further, there is some evidence that the longer children engage in such use, the more likely there is a substantial benefit.

Creativity

The first of the cognitive areas we address is creativity. *Fool's gold* implies that all uses of the computer stifle imagination.

> Creativity and imagination are prerequisites for innovative thinking, which will never be obsolete in the workplace. Yet a heavy diet of ready-made computer images and programmed toys appears to stunt imaginative thinking. Teachers report that children in our electronic society are becoming alarmingly deficient in generating their own images and ideas (p. 4).

An unsubstantiated statement that "teachers report" can be easily countered by opposing ones (either of similar reports from eras prior to classroom computers or present-day reports of creativity and inventiveness in technological environments). Further, we would agree that "a heavy diet of ready-made computer images and programmed toys" sounds unhealthy. But such opinions are less than satisfying. Instead, let us examine what empirical research says.

To do so, we have to again differentiate between different uses of computers. The use the term "programmed" recalls Elkind's rejection of computers because, "to be used by young children, computers have to be converted into teaching machines presenting programmed learning" (Elkind, 1987, p. 8). Elkind made the same errors that *Fool's gold* makes throughout the document, claiming that all computer applications are (or "have to be") similar in their nature and that the effects of this monolithic entity were pernicious.[7] As we document throughout the present article, most of the promising uses of computers have little to do with programmed learning or programmed toys (although "programmable toys" may be interesting—as long as children are involved with the programming). The philosophy and research that produces highly-controlled Instructional Learning Systems is quite distinct from the variety of perspectives that have produced other types of software designed to promote creativity.

Ignoring such distinctions, *Fool's gold* makes the general claim that computers damage creativity. They do cite empirical research on this issue.

> Unfortunately, like many other questions about the negative impact of computers in childhood, almost no research has been conducted on the potential for computers to stifle children's creativity and imagination. The results of the only well-known study on creativity, however, are not reassuring. It found that preschool children scored significantly lower on measures of creativity after using a popular software package designed to teach reading (p. 34).

This refers to a single study (Haugland, 1992), ostensibly with a negative result. However, they quote just half of the study; the same half that Healy (also cited in the report) is fond of quoting. This is, children exposed to what the author of the study, Sue Haugland, termed "non-developmental software" had significant losses in creativity. Little is made of the fact that these children did make gains in some areas. They were the only group in the study with significant gains in attention (concentration and short-term memory). An even more significant part that both Healy and *Fool's gold* leave out is that the 4- to 5-year-old children who worked with developmentally *appropriate* software had no loses in creativity and made significant gains in intelligence, non-verbal skills, structured knowledge, long-term memory, and complex manual dexterity. When reinforced with supplemental activities, children had gains in these areas as well as gains in verbal skills, problem solving, abstraction, and conceptual skills.

That's a lot to leave out! Furthermore, *Fool's gold* says that Haugland's is the only "well-known" study. This ignores numerous studies, including our own in the *Journal of Educational Psychology*, *American Educational Research Journal*, and *Educational Psychology Review* (Clements, 1986, 1991, 1995a, 1995b; Clements & Gullo, 1984). These articles present or review research that concurs that software such as drill and practice has little positive effect on creativity, but other types of software, including Logo, word processing, graphics, and "knowledge creation" and communication software can have a significant positive impact on a wide variety of measures of creativity. And please do not just take our word for it. First, there are several similar studies, each showing gains in at least some facets of creativity (Alchin, 1993; Horton & Ryba, 1986; Reimer, 1985; Vaidya & McKeeby, 1984). Finally, a frequent critical reviewer of computers in education concluded that at least some components of creativity are amenable to development within computer environments (Roblyer, Castine, & King, 1988).

Let us examine a few studies in more detail. Computer drawing experience appears to allow at least some children to create more elaborate pictures than those that they can create by hand. This creation, in turn, suggests to the children that they modify their ideas. Finally, they transfer components of these new ideas to art work on paper (Vaidya & McKeeby, 1984). Such computer drawing is appropriate for children as young as 3 years, who show signs of developmental progression in the areas of drawing and geometry during such computer use (Alexander, 1984; Clements & Nastasi, 1992; Tan, 1985).

In a similar vein, one early study documented an increase in figural creativity following Logo experience (Clements & Gullo, 1984). Later studies showed similar effects, although gains in some were moderate (Clements & Nastasi, 1992; Reimer, 1985; Roblyer et al., 1988; Wiburg, 1987) and occasionally nonsignificant (Mitterer & Rose-Drasnor, 1986; Plourde, 1987). Another study reported significant gains in creativity, noting that Logo students more fully developed their graphic compositions in completeness, originality, and drawing style (Horton & Ryba, 1986). At least one critical component of creativity, originality, has been consistently and positively affected in every study (Clements, 1986, 1991, 1995b; Clements & Gullo, 1984; Hlawati, 1985; Horton & Ryba, 1986; Plourde, 1987; Reimer, 1985; Wiburg, 1987). These results provide further evidence that Logo work enhances higher-order creative processes.

One might argue that computers could also run mind-numbing drill or video games. Of course. Logo can be used in most uncreative ways, by both teachers and students. Again, it is the cultural context and individual appropriation that engenders creativity or lack of it, given the tools available. If a poem or book report is boring, we do not blame the paper and pen. There are many ways to conceptualize and measure creativity, including creative thinking and learning in a variety of subject matter domains. Whether using computers to read or write, to acquire knowledge and insight into science, mathematics, and other areas through design (Campione, Brown, & Jay, 1992), to build a shared knowledge data base (Scardamalia & Bereiter, 1992), or to express oneself to learn content in a new medium (the focus of several succeeding sections), computers can support the expression and development of creativity.

Ironically, in the subsequent section of *Fool's gold*, the authors wax emotional about "reverence for the beauty and goodness of life [that can]…inspire older students to feel a devotion to truth" (p. 35). Their statements regarding computers and creativity veer far from such lofty goals. We now turn to two well-researched subject matter areas, literacy and mathematics.

Language and Literacy

Not surprisingly, computer-facilitated increases in social interaction help generate increased use of language. Preschoolers' language activity,

measured as words spoken per minute, is almost twice as high at the computer as at any of the other activities, including playdough, blocks, art, or games (Muhlstein & Croft, 1986). In general, the classroom computer is a valuable resource in facilitating language use, particularly interactional language functions (Kent & Rakestraw, 1994).

Computer graphics is an especially generative environment (Escobedo, 1992; Hutinger et al., 1998). For example, children in a nursery setting tell longer and more structured stories following a computer graphics presentation than following a static presentation or no stimulus (Riding & Tite, 1985). Working within a language experience context, 3- and 4-year-old children verbalized (i.e., dictated) significantly more about their Logo computer pictures than about their hand-drawn works (Warash, 1984). Research with Logo also indicates that it engenders interaction and language rich with emotion, humor, and imagination: (Genishi et al., 1985). Children were clearly and directly responsive to other children's requests for information. Experience with Logo embedded in a narrative context similarly enhances language-impaired preschool children's perceptual-language skills (Lehrer & deBernard, 1987) and increases first graders' scores on assessments of visual-motor development, vocabulary, and listening comprehension (Robinson, Gilley, & Uhlig, 1988; Robinson & Uhlig, 1988).

Reports such as these help allay the fear that computers will de–emphasize play, fantasy, and the corresponding rich use of language. When children are in control, they create fantasy in computer programs beyond the producers' imaginations (Escobedo, 1992; Wright & Samaras, 1986).

Computers can also help special populations (Cognition and Technology Group at Vanderbilt, 1998; Howard, Greyrose, Kehr, Espinosa, & Beckwith, 1996; Hutinger et al., 1998; Hutinger & Johanson, 2000; Lehrer & deBernard, 1987; McCormick, 1987; Schery & O'Connor, 1997; Walker, Elliott, & Lacey, 1994). We will not review this literature in depth, as it is one area in which *Fool's gold* supports computer use.

Many expert teachers believe that certain software programs can not only assist in language development, but can become languages for children. For example, in the famous early childhood classrooms in Reggio Emilia, as well as in the classroom of 5-year-olds taught by an expert teacher-researcher, children have learned to use artistic software as another of the "100 languages of children" (Oken-Wright, 1999). I asked Oken-Wright to expand on why

she believed computers offered a particularly helpful technology for her students. She responded she was not sure, but reflected on the issue using an experience with her own daughter. At five years of age, she did a marvelous series of *Kidpix* drawings when she was in my classroom every morning before school. She was having a tough time in Kindergarten with pencil and paper (they wanted lower case letters on lines, and she wasn't ready; and she wanted her drawings to reflect the image in her mind, and they couldn't help her). *Kidpix* became a real language for her. She drew in response to projects she saw going on in my classroom. She drew her memories. She drew communications for friends and families. She drew stories and dreams. This year she is happier in school and doing better. She has not drawn a single *Kidpix* piece all year! This is not to say *Kidpix* is only good for crises...but if it feeds a child's intellect and soul as it did my daughter's, I think it must have some powerful affordances (Oken-Wright, personal communication, 2001).

These same advantages allow computer-assisted instruction (CAI) drills and tutorials to help students develop prereading and reading skills. For example, computers can be successful in increasing a variety of verbal and language skills, especially when they provide scaffolding, or assistance, to the learner, which is gradually withdrawn (Shute & Miksad, 1997). This is especially true for language-delayed preschoolers.

Unique capabilities of CAI include those previously mentioned, as well as visual displays, animated graphics and speech, the ability to provide feedback and keep a variety of records, and individualization (Clements, 1994). When these capabilities are used, drill-and-practice software increases preschool and primary grade children's prereading or reading skills. For example, computer graphic representations of words enhance word recognition and recall in beginning reading (Shapira, 1995). As another example, a large effect (more than 1 standard deviation) of a research-based computer program has been shown on kindergartners' phonological awareness (Foster, Erickson, Foster, Brinkman, & Torgesen, 1994).

The amount of practice is important. A small number of sessions with simple readiness software may have little or no effect; for example, three 20-minute sessions with simple readiness software failed to show an effect on preschoolers' prereading concepts (Goodwin, Goodwin, Nansel, & Helm, 1986). In contrast, placing computers in kindergartners' classrooms for several months significantly increases reading readiness skills; placing them in the

home as well yields greater gains (Hess & McGarvey, 1987). About 10 minutes work with CAI per day can significantly benefit primary grade childrens' reading skill development (Childers, 1989; Lavin & Sanders, 1983; Murphy & Appel, 1984; Ragosta, Holland, & Jamison, 1981; Silfen & Howes, 1984; Stone, 1996; Teague, Wilson, & Teague, 1984). Similarly, preschoolers can develop such reading readiness abilities as visual discrimination and letter naming (Lin, Vallone, & Lepper, 1985; Smithy-Willis, Riley, & Smith, 1982; Swigger & Campbell, 1981). Other approaches, including computer-based interactive storybooks, appear quite promising (Hutinger et al., 1998; Hutinger & Johanson, 2000; Lewin, 1997; McKenna, 1998; Talley, Lancy, & Lee, 1997). For example, such storybooks can significantly close the gap between children who are "well-read-to" at home and those who are not (Talley et al., 1997). As a large component of a computer-based literacy program for preschoolers, such software significantly and positively affected a wide range of emergent literacy skills and knowledge, including specific print concepts, oral communication, retelling stories, recognizing letters, "reading" books, predicting and sequencing, making judgments, and listening (Hutinger et al., 1998).

Writing in light: Word processing. Another approach to early literacy is having children write and publish on the computer, one of the applications teachers of young children use most often (not including the most prevalent use, CAI drill, Becker, 1994; Cosden, 1988; Kromhout & Butzin, 1993). Recall that *Fool's gold* claims there is no evidence of the effectiveness of this approach. Once again, empirical evidence indicates that the capabilities of computer-based writing can encourage a fluid idea of the written word and free young children from mechanical concerns (Bangert-Drowns, 1993; Jones & Pellegrini, 1996). Kindergartners write and edit more like older students (Yost, 1998). In general, children using word processors write more, have fewer fine motor control problems, worry less about making mistakes, and make fewer mechanical errors (Clements, 1987a; Daiute, 1988; Hawisher, 1989; Kurth, 1988; Phenix & Hannan, 1984; Roblyer et al., 1988).

Such benefits result in increased abilities in composition. Young children can learn to competently revise their text when shown how to use the computer to edit their words. They improve their style using more descriptive phrases and also create better plots with climaxes and character descriptions (Wright, 1994). Additionally their attitude towards writing improves (Chang & Osguthorpe, 1990; Green, 1991; Holmes & Godlewski, 1995). Findings regarding holistic ratings of quality are mixed (Shaw,

Nauman, & Burson, 1994), but generally positive (Bangert-Drowns, 1989; Clements & Nastasi, 1992; Owston & Wideman, 1997). Quality increases if children are encouraged to use the word processor to edit their text in substantive ways (Wild & Ing, 1994).

Word processors also affect the social context of writing. When writing with a computer, compared to writing with paper, young children cooperatively plan, revise, and discuss spelling, punctuation, spacing, and text meaning and style (Dickinson, 1986, pp. 372-374). For example, Bernardo and Dan discussed the meaning of their text:

Bernardo: That doesn't make sense: "The Pilgrims were scared of the Indians. The found the food."

Dan: Oh yeah, I forgot!

Bernardo: "The found?" The Indians found.

Dan: Oh yeah.

Bernardo: You forgot the Indians. Now are you gonna try and go back and fit "Indians" in there? (pp. 372-374).

Even first graders are more "metacognitive" in their writing at the computer than with paper-and-pencil, talking more to each other about writing when they write with word processors than with paper and pencil (Jones & Pellegrini, 1996). Computer-based writing encourages peer collaboration, as well as self- and other-monitoring behaviors (Hine, Goldman, & Cosden, 1990). Learning disabled children working with a partner had fewer errors than those working alone. The partners monitored and helped each other. The shared availability of the text on the screen enabled participation by both partners in creating and editing text.

While the instructional approach may need to be modified, even young preschoolers may benefit from computer environments. For example, three-year-olds used the computer in a self-selected language experience activity for two years. Children showed steady improvement in spelling and story writing, including invented spellings (Moxley, Warash, Coffman, Brinton, & Concannon, 1997). When they were 4 years of age, they performed better than another group of children who engaged in similar activities but had not

received such experiences as 3-year-olds. Kindergartners increased writing and reading competencies working with a picture-word processor system that allowed them to write messages by simply pressing squares of picture-words on an electronic tablet without having to spell words or use extensive eye-hand coordination (Chang & Osguthorpe, 1990). Such findings are supported by the conclusions of another study: Children ages 4 through 7 can use word processors in a creative writing program to promote their developing writing abilities in many ways and in different ways at different stages of their development (Schrader, 1990)

Software that includes speech can be especially beneficial. Indeed, one of the longest-term studies of this type of technology involved the "talking typewriter," an early multimedia environment first implemented in the 1960s (Steg, Lazar, & Boyce, 1994). Children using the talking typewriter exceeded controls on many short-term measures, with competencies that often doubled those of control children (Israel, 1968). Similarly, using talking word processors, preschool to first-grade children were more able to express ideas, write simple sentences, and take risks in experimenting with their writing (Rosegrant, 1988). Voice-aided word processing acted as a scaffold for young children's writing by promoting the acquisition of several components of preschool literacy, developing an "inner voice" for constructing and editing text subvocally (Lehrer, Levin, DeHart, & Comeaux, 1987). This positively affects their writing. The more children in kindergarten and first grade used such spoken feedback, the higher their compositions were rated in length, grammatical cohesion, and lexical density (Jones, 1998; Jones & Pellegrini, 1996). However, teachers need to use computer speech wisely and assess children's readiness for voice-aided instruction. If they are in the earliest stages of invented spelling, computerized speech may not be helpful (Shilling, 1997). Another caution is that some young writers have the computer read their compositions a lot—so much so, that in one study, children using talking word processors wrote shorter compositions than those using word processors without speech, although both wrote more than paper-and-pencil groups (Kurth & Kurth, 1987). Later in the year, better readers listened to the computer less. Poor readers continued to use the synthesizer to read their stories. Thus, speech synthesis may be most important for beginning writers or less able readers (Kurth, 1988).

Word processing can have disadvantages. For example, first graders may benefit more from spelling practice involving handwriting than typing (Cunningham & Stanovich, 1990). However, none of the problems is long-lasting or insurmountable (Neufeld, 1989). Perhaps most important, effective

teaching and writing strategies have to be employed along with the technology (Becker, 1990). Realizing benefits also requires sufficient computer access and time (Reed, 1996). One group of researchers stated that if they had stopped their evaluation after a couple of months, they would have mistakenly concluded there were no effects. Only after one full year did the rich benefits emerge (Cochran-Smith, Kahn, & Paris, 1988).

As with all other computer and non-computer technologies or teaching strategies, computer writing can be misused in other ways. It can be the focus of instruction, a point made in *Fool's gold* but also in our previous reviews (Clements, Nastasi, & Swaminathan, 1993). We repeat, however, that banal instruction is conducted frequently with all media. The fact that some focus too much on the technology implies that we need to raise consciousness, not attempt to avoid the technology.

When used well, computer-based writing can be successfully integrated into a process-oriented writing program as early as first grade, and even younger students can use computers to explore written language. Computers can facilitate the development of a new view of writing and a new social organization (cooperative learning) that supports young children's writing. Combined with telecommunications, technology also can connect classrooms from across the world together in cooperative writing groups (Gustafsson, Mellgren, Klerfelt, & Samuelsson, 1999; Riel, 1994).[8] Software and teaching strategies that support the composing process, especially guiding prewriting, might be most beneficial for young writers. Children plan, write, discuss, and revise more frequently in such environments. They use the computer as a language arts learning tool. Finally, there are collateral benefits; the integration of an interactive literacy program not only increases young students' use of computers, bur also enhances their computer skills, computer self-efficacy, and enjoyment of computers (Ross et al., 2001).

Fool's gold's false dichotomy. Such a body of evidence stands in stark contraposition to the claims of *Fool's gold*. The report also argues, however, that academics for young children are inappropriate even if "successful." "In kindergarten, therefore, an emphasis on play and social skills—not premature pressure to master reading and arithmetic—seems most likely to prepare children for later academic success" (p. 9). Are these the only two approaches? Play or pressure for mastery? No. The latter is a loaded phrase. Who "masters" arithmetic in kindergarten? Who has not observed children's enthusiastic counting during the early years?

The growth of literacy in both the language arts and mathematics follows a developmental continuum. The inclusion of appropriate experiences in both spheres for children from preschool on is supported by the relevant leading organizations, the National Association for the Education of Young Children (the creators and main defenders of "developmentally appropriate" experiences for young children), the International Reading Association, and the National Council of Teachers of Mathematics (1998; National Council of Teachers of Mathematics, 2000) as well as by substantive research showing that early experiences (including early intervention for those who need additional support) are critical (Clements, Sarama, & DiBiase, in press). In the domain of reading, for example, the recent report from the National Research Council (Snow, Burns, & Griffin, 1998) reported that the majority of reading problems faced by adults could have been avoided or resolved in the early years of childhood. Thus, literacy forms a developmental continuum, and ignoring that continuum is no more developmentally appropriate than teaching the subjects by rote. And children who use the computer as a language arts learning tool improve their language, writing, and reading competencies (Green, 1991; Lehrer & deBernard, 1987).

Mathematics and Reasoning

Even accepting a developmental continuum for literacy, *Fool's gold*'s attack on early "abstract" or "symbolic" learning experiences might seem to have some prima facie validity for mathematics. As with literacy, however, both research and the wisdom of expert practice indicate that young children can and should engage in mathematics and that computers can play a facilitative role (Clements et al., in press).

As with literacy skills, children can use CAI to practice arithmetic processes and to foster deeper conceptual thinking, including a valuable type of "cognitive play" (Steffe & Wiegel, 1994). Drill and practice software can help young children develop competence in such skills as counting and sorting (Clements & Nastasi, 1993). Indeed, some reviewers claim that the largest gains in the use of CAI have been in mathematics for preschool (Fletcher-Flinn & Gravatt, 1995) or primary grade children, especially in compensatory education (Lavin & Sanders, 1983; Niemiec & Walberg, 1984; Ragosta et al., 1981). Again, 10 minutes per day proved sufficient for significant gains; 20 minutes was even better. This CAI approach may be as, if not more, cost

effective as traditional instruction (Fletcher, Hawley, & Piele, 1990) and as other instructional interventions, such as peer tutoring and reducing class size (Niemiec & Walberg, 1987). Properly chosen, computer games may also be effective. Kraus (1981) reported that second graders with an average of one hour of interaction with a computer game over a two week period responded correctly to twice as many items on an addition facts speed test as did students in a control group.

Preschoolers and math. How young can children be and still obtain such benefits? Three-year-olds learned sorting from a computer task as easily as from a concrete doll task (Brinkley & Watson, 1987-88a). Reports of gains in such skills as counting have also been reported for kindergartners (Hungate, 1982). However, our position is that use of drill, especially with young children, should be used carefully and in moderation. There are possibilities that children will be less motivated to perform academic work following drill (Clements & Nastasi, 1985) and that their creativity may be harmed by a consistent diet of drill (Haugland, 1992). Also, exclusive use of such drill software would do little to achieve the vision of the National Council of Teachers of Mathematics (2000) that children should be mathematically literate in a world where mathematics is rapidly growing and is extensively being applied in diverse fields. What other approaches help achieve that vision?

Computer manipulatives. In one approach, children explore shapes using general-purpose graphics programs or "computer manipulatives." Researchers observing such use observe that children learn to understand and apply concepts such as symmetry, patterns and spatial order (Wright, 1994). Computer manipulative programs allow children to perform specific mathematical transformations on objects on the screen. For example, whereas physical base-ten blocks must be "traded" (e.g., in subtracting, students may need to trade 1 ten for 10 ones), students can break a computer base-ten block into 10 ones. Such actions are more in line with the *mental actions* that we want students to learn. The computer also links the blocks to the symbols. For example, the number represented by the base-ten blocks is dynamically linked to the students' actions on the blocks, so that when the student changes the blocks the number displayed is automatically changed as well. This can help students make sense of their activity and the numbers.

So, computer manipulatives can provide unique advantages (Clements & Sarama, 1998; Sarama, Clements, & Vukelic, 1996). They can allow children to

save and retrieve work, and thus work on projects over a long period (Ishigaki et al., 1996). Computers can offer a flexible and manageable manipulative, one that, for example, might "snap" into position. They can provide an extensible manipulative, which you can resize or cut. They can help connect concrete and symbolic representations through multiple, linked representations and feedback, such as showing base-ten blocks dynamically linked to numerals. Computers can record and replay students' actions, encouraging students' reflection. Finally, computers can help bring mathematics to explicit awareness, for example, by asking children to consciously choose what mathematical operations (turn, flip, scale) to apply.

A couple of additional illustrations of these advantages might be useful (Sarama et al., 1996). When a group of kindergartners were working on a pattern with physical manipulatives, they wanted to move it slightly on the rug. Two girls (four hands) tried to keep the design together, but they were unsuccessful. Marisssa told Leah to fix the design. Leah tried, but in re-creating the design, she inserted two extra shapes and the pattern wasn't the same. The girls experienced considerable frustration at their inability to get their "old" design back. Had the children been able to save their design, or had they been able to move their design and keep the pieces together, their group project would have continued. Indeed, moving a design to another area of the screen was the most common reason for using the "glue" tool with these kindergartners.

Piaget, movement, and turtle geometry. *Fool's gold* states that Piaget and others have shown that young children learn intuitively through their bodies. It claims that "Geometrical relationships and multiplication tables, for example, can be taught through creative motion or rhythmic games" (p. 54). The latter of the two, multiplication tables, is difficult to consider seriously. If the report had stated "multiplication," it is conceivable that motion games could play some viable role within the Piagetian framework they espoused. However, for learning "tables" (multiplication as "facts"), possible strategies are even less clear (motion games as sugar-coating for drills are not viably learned through one's body). As usual, the report has ignored specific research on the relationships that underlie multiplication and how multiplication is learned (Steffe, 1994).

There is validity to the claim that geometric relationships can and should be learned through bodily movement. Ironically, that perspective has been the foundation of perhaps the most well-researched area of computer use in education, turtle geometry. Seymour Papert (1980) invented the turtle

because it was “body syntonic.” A large research corpus on Logo and mathematics learning is based on the position that students construct initial spatial notions not from passive viewing, but from actions, both perceptual[9] and imagined, and from reflections on these actions (Piaget & Inhelder, 1967). These are valuable active experiences for students; however, unless these experiences are mathematized[10] they remain only intuitions. There are several ways to help students reflect on and represent these experiences; research indicates that Logo’s turtle geometry is one potent way (Clements & Sarama, 1997).

Logo environments are in fact action-based. By first having children form paths and shapes by walking, then using Logo, children can learn to think of the turtle’s actions as ones that they can perform; that is the turtle’s actions become “body syntonic.” But why not just draw it without a computer? There are at least two reasons. First, drawing a geometric figure on paper, for example, is for most people a proceduralized process. This is especially true for young children, who have not re-represented the sequential instructions that they implicitly follow. Then, they cannot alter the drawing procedure in any substantive manner (Karmiloff-Smith, 1990), much less consciously reflect on it. In creating a Logo procedure to draw the figure, however, students must analyze the visual aspects of the figure and their movements in drawing it, thus requiring them to reflect on how the components are put together. Writing a sequence of Logo commands, or a procedure, to draw a figure “…allows, or obliges, the student to externalize intuitive expectations. When the intuition is translated into a program it becomes more obtrusive and more accessible to reflection” (Papert, 1980, p. 145). That is, students must analyze the spatial aspects of the shape and reflect on how they can build it from components.

And they do. Primary-grade children have shown greater explicit awareness of the properties of shapes and the meaning of measurements after working with the turtle (Clements & Nastasi, 1993). They learn about measurement of length (Campbell, 1987; Clements, Battista, Sarama, Swaminathan, & McMillen, 1997; Sarama, 1995) and angle (Browning, 1991; Clements & Battista, 1989; du Boulay, 1986; Frazier, 1987; Kieran, 1986; Kieran & Hillel, 1990; Olive, Lankenau, & Scally, 1986). One microgenetic study confirmed that students transform physical and mental action into concepts of turn and angle in combined off- and on-computer experiences (Clements & Burns, 2000). Students synthesized and integrated two schemes, turn as body movement and turn as number, as originally found by Clements, Battista,

Sarama, & Swaminathan (1996). They used a process of psychological curtailment in which students gradually replace full rotations of their bodies with smaller rotations of an arm, hand, or finger, and eventually internalized these actions as mental imagery.

Logo is not easy to learn. However, as one primary-grade student declared, "This picture was very hard and it took me 1 hour and 20 minutes to do it, but it had to be done. I liked doing it" (Carmichael, Burnett, Higginson, Moore, & Pollard, 1985, p. 90). Moreover, when the environment is gradually and systematically introduced to the children and when the interface is age-appropriate, even young children learn to control the turtle and benefit cognitively (Allen, Watson, & Howard, 1993; Brinkley & Watson, 1987, 1988b; Clements, 1983/1984, p. 402; Cohen & Geva, 1989; Howard, Watson, & Allen, 1993; Stone, 1996; Watson, Lange, & Brinkley, 1992). Thus, there is substantial evidence that young children can learn Logo and can transfer their knowledge to other areas, such as map-reading tasks and interpreting right and left rotation of objects. They reflect on mathematics and their own problem-solving. For example, first grader Ryan wanted to turn the turtle to point into his rectangle. He asked the teacher, "What's half of 90?" After she responded, he typed RT 45. "Oh, I went the wrong way." He said nothing, keeping his eyes on the screen. "Try LEFT 90," he said at last. This inverse operation produced exactly the desired effect (Kull, 1986).

These effects are not limited to small studies. A major evaluation of a Logo-based geometry curriculum included 1,624 students and their teachers and a wide assortment of research techniques, pre and post paper-and-pencil testing, interviews, classroom observations, and case studies (Clements & Battista, in press). Across grades K-6, Logo students scored significantly higher than control students on a general geometry achievement test, making about double the gains of the control groups. These are especially significant because the test was paper-and-pencil, not allowing access to the computer environments in which the experimental group had learned and because the curriculum is a relatively short intervention, lasting only six weeks. Other assessments confirmed these results, and indicated that Logo was a particularly felicitous environment for learning mathematics, reasoning, and problem solving.

These studies and hundreds of others (Clements & Sarama, 1997) indicate that Logo, *used thoughtfully*, can provide an additional evocative context for young children's explorations of mathematical ideas. Such "thoughtful use" includes structuring and guiding Logo work to help children form

strong, valid mathematical ideas (Clements & Battista, in press). Children often do not appreciate the mathematics in Logo work unless someone helps them see the work mathematically. Effective teachers 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 ideas explicit for children. They help children build bridges between the Logo experience and their regular mathematics work (Clements, 1987b; Watson & Brinkley, 1990, 1991). In summary, research indicates that working with Logo can help students construct elaborate knowledge networks (rather than mechanical chains of rules and terms) for geometric topics. It does not always do so, because like any other medium of expression, it operates within a social and educational context. But empirical research confirms the potential.

Educational technologies, methodologies, and content. Before we leave the realm of mathematics, another issue, ignored by *Fool's gold*, should be addressed. The nature of our educational content and methodology has always been, and remains, influenced by what technology is used (Papert, 1998). Papert asks: Why is the quadratic equation of the parabola included in the mathematical knowledge every educated citizen is expected to know? The explanation that it is "good," or "important," mathematics is inadequate: The curriculum includes only a minute sliver of the total body of such mathematics. The real reason is that it matches the technology of pencil and paper. Students can draw the curve on grid paper and teachers can verify that the assignment has been done correctly. An alternative mathematical education might consist of creating, modifying, or controlling dynamic computational objects. In this context, Papert argues, the parabola may be first encountered by children creating a videogame as the trajectory of a thrown object. The natural first formalism for the parabola in this case would be an expression, in a computational language, "the path followed when horizontal speed and vertical acceleration are both constant." Such a formalism is arguably more concrete (Clements, 1999), intuitive, and motivating than quadratic equations. Papert's (1998) experiments support this position by showing that the dynamic definition is indeed accessible even to elementary school children who are given the opportunity to acquire a degree of computational competence. Whether Papert's particular example or vision is right or wrong, it is clear that available technologies have always influenced the content and methodology of mathematics (Lukens, 1984), and we believe it follows that content—for mathematics and other subject matter areas—must thus be consistently reconsidered.

Science and simulations. *Fool's gold* makes the point that:

> Children thus need to experience the fullness of the world around them. Computer simulations or "content delivery" are poor substitutes for hands-on lessons—outdoors, if possible—in botany, zoology, chemistry, and physics. What young children learn first in their bodies and later in heartfelt sympathy with nature does, with time and instruction, later mature into conscious understanding. Educational shortcuts that attempt to bypass the physical and emotional stages of learning defy science. (p. 10)

The need for direct experience is easily accepted (and is a critical component of the complete educational environment in most studies reviewed here). Not so obvious is that early bodily experiences "mature into conscious understanding." Bypassing physical and emotional stages of learning is unwise, but so is relying on "maturation" of early experiences. As we have known since the time of Dewey (1963), any experience can be educative or miseducative. And it is not the experience but the reflection on that experience that makes it educative. Computers can put children in touch with simulations that help them elaborate on natural experiences (e.g., comparing a chicken egg incubating with a computer simulation of a developing chick inside the egg Sheingold, 1986), reflect on concrete experiences by allowing them greater control of the situation (e.g., comparing a physical pendulum and a computer simulation, Clements, 1989), extend physical experiences (e.g., simulations of micro-organisms in the human body, Mikropoulos, Kossivaki, Katsikis, & Savranides, 1994), and provide experiences that allow children to compare and contrast everyday beliefs about force and motion with formal physical knowledge (planetary motion change of gravity, McCauley, 1983, 1984; White, 1981). In Vygotskian terms, these catalyze the synthesis of scientific with spontaneous knowledge. One study compared three groups of third graders, receiving science instruction that was hands-on, hands-on with computer-assisted instruction, and limited to the textbook. Both groups with hands-on activities outscored the textbook group. However, the group that included both hands-on and computer activities also outscored the group that only used hands-on activities (Gardner, Simmons, & Simmons, 1992).

We make a final observation regarding simulations and "concrete" manipulatives. No longer should all computer applications be considered virtual worlds. For example, in Lego-Logo, children create Lego structures, including lights, sensors, motors, gears, and pulleys, and they control their structures with the computer. For example, Kevin started, as many other

students do, by building a car out of LEGO (Resnick, 1988). The car moved forward a bit…and then the motor fell off and vibrated across the table. The movement interested Kevin. He wondered if he could use the vibrations to power the vehicle. He mounted a motor on a LEGO base and learned that with the computer he could control the walker—it turned right when the motor rotated in one direction, left when it rotated in the other. There are but a few studies on LEGO-Logo, but they indicate that such experiences can positively affect mathematics and science achievement and competencies in higher-order thinking skills (Browning, 1991; Enkenberg, 1994; Flake, 1990; Weir, 1992). LEGO-Logo appears to provide authentic learning tasks (Lafer & Markert, 1994), motivate and empower students as well, and possibly develop self-esteem (Silverman, 1990; Weir, 1992). This may be because LEGO-Logo provides an academic setting in which students can develop their own goals (Browning, 1991; Lai, 1993; Weir, 1992). More research is needed before firm conclusions can be drawn about this particular application, but it is a clear illustration that there is no dichotomy between computers and hands-on learning environments.

Conclusions

To the long list of reported positive effects of computer use with children, add problem-solving skills (Nastasi et al., 1990), decision-making ability, understanding of cause and effect, (Goodwin, Goodwin, & Garel, 1986; Hutinger & Johanson, 2000), and longer attention spans (Fatouros, 1995; Haugland, 1992; Hutinger & Johanson, 2000). Special needs preschool children in one study made progress in all developmental areas, including social-emotional, fine motor, gross motor, communication, cognition, and self-help. A measure of development showed that upon joining the program, children were making an average gain of .52 months per month. While participating in the computer-based program, children were making an average rate of progress of 1.81 months per month. After participation, 14 of the 15 children who participated for two years doubled their per month gain; 6 had developmental scores that exceeded their chronological scores for the first time in their lives (Hutinger & Johanson, 2000). For these children, 100% of both parents and teachers indicated that they saw improvements across the same wide variety of areas of development. Results indicated that the computer made a unique contribution. Across 11 common classroom activities, including play, books, computer, art, and snack time, results

showed that computer use was most often followed by desirable behaviors such as sharing, communicating, taking turns, and focusing and least likely to be followed by aggression (Hutinger & Johanson, 2000).

These results and those described in the previous two sections on social, emotional, and cognitive development, certainly call into question a main claim of the *Fool's gold* report:

> Those who place their faith in technology to solve the problems of education should look more deeply into the needs of children. The renewal of education requires personal attention to students from good teachers and active parents, strongly supported by their communities. It requires commitment to developmentally appropriate education and attention to the full range of children 's real low-tech needs—physical, emotional, and social, as well as cognitive. (p. 4)

Hoping the authors will assent that even those who disagree with them may indeed have looked "deeply into the needs of children," we assert, again, that those who have blind "faith in technology to solve the problems of education" are few—the *Fool's gold* report exaggerates this. We agree that education needs renewal, but, as we have made clear, the empirical evidence supports thoughtful use of computers in settings that include "personal attention to students from good teachers and active parents." Indeed, it has been observed that in elementary to secondary classrooms in which technology is used reflectively, teachers have more time to spend with individuals and small groups of students (e.g., Lesh & Lesh, 1989; Schofield, 1995). They are more engaged with students' thinking and learning. Students believe they receive more attention and help from their teachers (Schofield, 1995).

We leave this section with a brief consideration of equity. The "digital divide separating children in socioeconomically advantaged homes from children in socioeconomically disadvantaged homes is mammoth" (Becker, 2000, p. 56). For example, about 22% of children living in families with annual incomes under $20,000 had a home computer in 1998, compared with 91% of children living in families with incomes over $75,000 (Becker, 2000). Logically, the *Fool's gold* authors would have to take the position that the lower-income children are far better off in this case. We contend that this would constitute a sour consolation to less advantaged families, especially considering that certain uses of computers can facilitate children's learning and development[11] and that higher-income schools, compared to lower-

income schools, use computers in just these more intellectually powerful ways (Becker, 2000). Although lower-income schools have approximately the same ratio of computers to students, teachers in these schools use technology more for traditional applications such as drill and practice. *Fool's gold's* undifferentiated condemnation of computers implies only a public policy of less financial support for computer presence in schools. We believe such a policy would increase the pernicious effects of the digital divide, as we assume that, even with a decrease in such financial support, high-income children would continue to have access at home and would continue to use computers in powerful ways at school. We believe that the equitable strategy is to provide teachers in lower-income schools with time, practice, and support to develop methods for using challenging software successfully with their students (Becker, 2000).

GENERAL USE OF COMPUTERS AND CHILDREN'S DEVELOPMENT

A theme that runs though *Fool's gold* is that "many schools have cut already minimal offerings in these areas [e.g., the arts] to shift time and money to expensive, unproven technology" (p. 3). There are two problems with this statement.

First, let us consider "expensive, unproven technology." We have already seen there is ample evidence of positive uses of technology and their educational benefits. More important, our comfort with textbooks belies the fact that one could better apply the phrase "expensive, unproven technology." to most textbooks currently in use. We shall return to this point later; here we point out that most curriculum materials presently in use are not based on research nor evaluated in any substantive way (Clements, in press) and if one argued they are "proven" because we've used similar approaches for a while, then what has been proven is that traditional approaches do not work. People who presume traditional approaches have been "proven successful" are:

> ignoring the largest database we have. The evidence indicates that the traditional curriculum and instructional methods in the United States are not serving our students well…the long-running experiment we have been conducting with traditional methods shows serious deficiencies. (Hiebert, 1999, p. 13)

Second, what research is there that the unfortunate de-emphasis on the arts is the result of the introduction of computers? The de-emphasis began

earlier, with curriculum reform movements of the 1970s and the rise of "basics" and standardized testing (Fowler, 1988). Further, present school use is small, at most. A survey in Silicon Valley, where computer use might be expected to be as high as any location in the U.S., found that although 70% of teachers in Kindergarten through third grade had their students work on computers, the students' computer time averaged less than 10 minutes per day (Shields & Behrmann, 2000). Finally, in early childhood, one of the best uses of computers is to extend artistic experiences.

Fool's gold also states that computer use is insidious. "The computer—like the TV—can be a mesmerizing babysitter" (p. 3). This is technocentricism again: "The computer" is not a single, monolithic entity. Certain video games do appear to mesmerize some populations. If you are discussing these video games, say so, and do not generalize to a variety of different computer uses. If you mean to include the kind of high-quality educational experiences that have proven effective, then there is evidence this statement is not only exaggerated, but just plain wrong. While they can be engaging, especially guided by a caring adult, the empirical evidence suggests that, unfortunately but unsurprisingly, children at home do not engage in such educational experiences as frequently as they play games (Becker, 2000). The *Fool's gold* authors say as much in a succeeding paragraph:

> And a new study from the American Association of University Women Educational Foundation casts doubt on the claim that computers automatically motivate learning. Many girls, it found, are bored by computers. And many boys seem more interested in violence and video games than educational software. (p. 4)

We agree this sometimes happens; however, usually, girls are just as interested and just as or more effective at computer tasks (Yelland, 1998). A recent review concluded that "With the narrowing of the gender gap in home computer use, early fears that girls are turned off by computer technology appear unfounded" (Subrahmanyam et al., 2000, p. 127); "as the array of nongame applications widens…girls now report using home computers as often, and with as much confidence, as boys" (p. 130). Overall, girls are just as interested in computers, but more likely to use them for education, schoolwork, communication, compared to boys' engagement in entertainment (Wartella, O'Keefe et al., 2000). More important, many children prefer paperbacks and comic books of low literary quality to high-quality novels, but we do not reject books. The argument is specious. We need social-cultural and political movements to motivate and fund production of high-quality content for all media and broad dissemination of research-based

knowledge of negative and positive uses of all media. Media literacy training for parents and children can result in young children becoming less vulnerable to the negative aspects of all media and able to make wise choices (American Academy of Pediatrics, 1999).

Unfounded, and unsupported, arguments are woven throughout *Fool's gold*. Another example is: "Computers are perhaps the most acute symptom of the rush to end childhood." (All uses of computers? More than the pervasive sexuality and violence present in other media?—[Wartella, Scantlin, Kotler, Huston, & Donnerstein, 2000]) Perhaps the oldest is that they are "developmentally inappropriate" (Barnes & Hill, 1983): "The national drive to computerize schools, from kindergarten on up, emphasizes only one of many human capacities, one that naturally develops quite late—analytic, abstract thinking—and aims to jump start it prematurely" (p. 19). "Only around puberty does the child's dominant mode of learning finally shift to the conscious intellect, as abstract considerations of logic and cause-and-effect reasoning gradually begin to hold sway in his mind" (p. 7).

Here the authors drag out old concerns already addressed in the literature, that children must reach the stage of concrete operations before they are ready to work with computers, or that children will be harmed by "abstract thinking." These ideas are based on rigid (and frequently discredited) interpretations of Piagetian theory. For decades, research has found that preschoolers are more competent than has been thought and can, under certain conditions, exhibit thinking traditionally considered "concrete" or "abstract" (Gelman & Baillargeon, 1983; Gelman & Williams, 1997). Furthermore, research shows that even young preoperational children can use and benefit from appropriate computer programs (Clements & Nastasi, 1992).

A related concern is that computer use demands symbolic competence; that is, that *computers* are not concrete. This ignores, however, that much of the activity in which young children engage is symbolic. They communicate with gestures and language, and they employ symbols in their play, song, and art (Sheingold, 1986). By age of 5, children have "first draft knowledge" of symbolization in language pictures, three-dimensional objects, dance, music, pretend play, as well as numerical and logical knowledge (Gardner, 1983). Furthermore, the "symbols" of computers can include graphics, voice, music, and even connections to Lego blocks! We have seen, in previous sections, that computers support valuable symbolization and connections between symbols and meaning in both literacy and mathematics.

Moreover, what is "concrete" to the child may have more to do with what is meaningful and manipulable than with physical characteristics (Clements & McMillen, 1996). One study compared a computer graphic felt board environment, in which children could freely construct "bean stick pictures" by selecting and arranging beans, sticks, and number symbols, to a real bean stick environment (Char, 1989). The computer environment actually offered equal, and sometimes greater control and flexibility to young children. Both environments were worthwhile, but one did not need to precede the other. Other studies show that computers enrich experience with regular manipulatives. Third-grade students who used both manipulatives and computer programs, or software, demonstrated a greater sophistication in classification and logical thinking, and showed more foresight and deliberation in classification, than did students who used only manipulatives (Olson, 1988). These studies support our earlier conclusions about the potential of computer manipulatives.

In conclusion, computers can support developmentally appropriate educational experiences (Mikropoulos et al., 1994). We define this term as follows: "Developmentally appropriate means challenging but attainable for most children of a given age range, flexible enough to respond to inevitable individual variation, and, most important, consistent with children's ways of thinking and learning" (Clements et al., in press). *Therefore, the key question is not if computers are "concrete," but whether they provide experiences that facilitate children's learning in many spheres in ways consistent with children's development.* Available research indicates that—used wisely—they can. And they do so not just by promoting specific learning, but also by promoting play (Anderson, 2000; Escobedo, 1992; Garaigordobil & Echebarria, 1995; Hoover & Austin, 1986; Ishigaki et al., 1996; Kokish, 1994; Muhlstein & Croft, 1986; Picard & Giuli, 1985; Wright & Samaras, 1986).

Fool's gold also raises concerns about physical development. Putting such concerns in historical perspective is an initial interesting exercise. There is a standard progression of public concerns and research questions as each new innovation is adopted by society (Wartella & Jennings, 2000; Wartella & Reeves, 1983). As the medium is being developed, the concern is how much and in what ways it is being used. Attention then shifts to the possibly deleterious effects of the medium on physical and emotional health. Finally, the effects of the content on values, attitudes, and behavior become the dominant concerns. The first wave of research is motivated by concerns expressed by parents and educators about the supposedly inordinate

amount of time children occupy themselves with the new medium. This concern turns the focus of attention to physical and emotional health effects. In the first decades of this century, there was concern about children viewing films in dark, possibly unsanitary, movie houses. There was concern that listening to radio would affect children's hearing. Television was accused of causing bad eyesight and of emitting harmful radiation. Finally, society and researchers have focused their attention on the effects of the media's content upon children's morality—"gangsterism" on radio, sex and violence on films, and so on. In each case, studies concluded that the media "would affect individual children differently depending on the child's age, sex, predispositions, perceptions, social environment, past experiences, and parental influence" (Wartella & Jennings, 2000, p. 33). For example, children who have unsatisfactory relationships with their family and peers are most likely to retreat to the fantasy of aggressive content on various media. Most important, the effects on children differed with the content, ranging from negative effects on cognitive style to positive effects on cognitive skills, academic performance, and social relationships (Wartella & Jennings, 2000).

Fool's gold reiterates similar concerns, such as deleterious effects on vision. Declining eyesight due to a computer use is a popular complaint in Japan as well. However, analysis reveals that the distribution of video games began in 1985, and the decline in eyesight began in 1974, and therefore the link between the two is not clear (Ishigaki et al., 1996).[12] *Fool's gold* claims that computer research, requiring "reading long documents for meaning, requires the kind of visual skills and perceptual abilities that are generally not well-developed until about the age of 9" (p. 24). We are surprised both that long-term Internet research is rampant in our early childhood and primary grade classrooms and that this is the first time children are reading long documents for meaning. They quote Bill Gates of Microsoft as saying that because he likes to read from paper, he prints it out. It's not clear why the authors' recommendation is to end computer use as opposed to simply, using print outs when that is helpful or desired. Other health concerns are treated similarly.[13]

Let us be clear. Health concerns should be carefully considered and monitored. What we are objecting to is the use of individual, unnamed doctors, inappropriate anecdotes, and flawed logic, all compounded by the lack of solid research. Concerns such as repetitive stress injuries are important; however, reported injuries concern adults such as data entry specialists; more child-focused research is needed (Shields & Behrmann,

2000; Wartella, O'Keefe et al., 2000). Children should be given the same cautions as adults (Subrahmanyam et al., 2000), stated even more conservatively. Our main point is that if children, especially the young children on whom we are focusing, are typing on typewriters or computers, or cramping their hands writing with pens for that matter, without breaks for hours per day, we have an important societal and educational problem far beyond the issue of using old or recent technology. Children should not be in front of screens, a disproportionate amount of their day (Shields & Behrmann, 2000). Home exposure to commercial television and video games, especially those including inappropriate topics, might be the main targets of efforts to limit screen time. Further, we object to *Fool's gold*'s disregard of research evidence on positive effects, as some interactive media "has demonstrated an extraordinary potential to help children live healthier, safer lives (e.g., action-adventure computer games leading to a 77% decrease in diabetes-related emergency and urgent care clinical visits, compared to a control group of youngsters with an entertainment game at home, Wartella, O'Keefe et al., 2000).

Fool's gold attacks everything and everywhere it can, but we have attempted to show that these unqualified arguments are not convincing. Still, we accept the importance of their basic question: Should computers replace other experiences? The Alliance is connected to the Waldorf philosophy, which has some sound principles; for example, direct sensory experiences are important. Should computers replace such experience? Usually not (although simulations of dangerous situations may constitute exceptions). Let's look a bit deeper. How about extending and complementing such experiences? Is it better for children to interact with animals that are not in their locale using technology, or not at all? In this case, technology—whether televised nature programs, the Web, or disk-based programs—would benefit the goals of nature education. Even when children can interact with a natural environment, might there be a time when other technologies should be employed? Again, yes. Children who interact with technologies from books to television to computers can help find new information and explore possibilities. For example, they might manipulate a simulation that allows them to change ecologies for animals and study the results. This is saying no more than John Dewey did about "learning by doing." Yes, you learn by doing, but you learn well and deeply only when you reflect on your actions and experiences.

AREAS OF AGREEMENT

As we hope we have made clear, on some concerns and issues there are areas of agreement (with the caveat that some distinctions and elaborations must be appended). We mention six here.

We should support meaningful, "whole" development and learning for children. One main area of agreement is around general issues of development and learning. Page after page is spent providing a broad background consistent with a recent early childhood pedagogical study (Bowman, Donovan, & Burns, 2001). Unfortunately, the *Fool's gold* authors link this background directly to computer issues. Ironically, the same literature that supports meaningful, holistic development and learning, underlies many theorists' and developers' efforts to create computer environments that uniquely facilitate research-based pedagogies.

Technology can help children with disabilities. The *Fool's gold* authors agree that for children with certain disabilities, technology offers critical benefits. This is a typical position of those biased against engineering and technology; when the benefit is unarguable, make an exception, ignoring the similarities of children with and without disabilities, all of whom benefit in various ways, and all of whom are harmed by inappropriate use.

There are inappropriate justifications for early computer use. "Must five-year-olds be trained on computers today to get the high-paying jobs of tomorrow?" (p. 4). We agree they do not. This argument—rarely made by those actually in the field—is as misleading and unfortunate as the argument that college guarantees graduates a larger income. Although a degree may increase earnings, the justification for a college education should be based on the value of an educated citizenry and the realization of each individual's potential. Likewise, use of computers with children is more about realizing their potential across the many critical areas of development, including the intellectual and social-emotional domains. When computers contribute to this development, they should be used. When they do not, they should not be used.

There are inappropriate uses of computers. We addressed this theme throughout this article; indeed, on this score we agree to a great degree. For example, in a review we critically questioned "aspects of ILS's, especially diminished teacher and student control. In too many cases, ILS's represent a

triumph of bureaucratic efficiency over young children's development" (Clements et al., 1993). We have similarly raised concerns about aggression and inequities (Clements, 1985), and there is every reason to limit all children's exposure to violence in all media (especially those at risk developmentally and socially). The intensity of our response here has more to do with our objection to the way the message was delivered and its foundation, than on the ratio of issues on which we do or do not disagree.

Why have we not defended the Internet, a constant target of *Fool's gold*? In a minor way, we have; some of the literacy work that involves writing for other audiences has used such technologies. However, our lack of attention to the Internet reflects our belief that we should reserve summative judgment until empirical evidence concerning advantages or disadvantages of *specific uses* is amassed. In lieu of such evidence, it may be useful to consider anecdotal reports, such as *Fool's gold's* description of students' ostensibly limited understanding of the Renaissance. It certainly gives one pause, although we seriously doubt that disconnecting the students and providing them with the "favored books" listed would guarantee a deep understanding any more than providing Internet access would. The teacher and curriculum are undoubtedly important factors here, possibly leading to the number of positive anecdotes about students' learning with the Internet.[14]

Total time in front of screens should be limited. The time children spend in front of a screen should be limited. We emphasize that commercial TV and inappropriate video games are the largest contributors to such time, with children ages 2 to 7 spending from 2 to 3 hours per day in front of a screen (Subrahmanyam et al., 2000), and should be the first to be curtailed (Clements & Nastasi, 1993; Shields & Behrmann, 2000). Then, positive uses should be limited to no more than one to two hours a day (American Academy of Pediatrics, 1999). However, strict time limits in an early childhood classroom (e.g., 5 or 10 minutes per child and then they must quit) is not wise. In one large study, such strict rules generated hostility and isolation instead of the usual positive effects of the computers on social communication; the strict limits kept children from communicating and sharing (Hutinger et al., 1998). Child-centered control was again the more positive path.

Money is often spent unwisely. We have written about the unfortunate ways that most curriculum and software materials are developed and marketed (Clements, in press; Clements & Nastasi, 1992). Large sums of

money should not be spent without reflection on educational priorities. If high-priority goals can be achieved well with specific computer applications, then detailed planning should precede any purchase. (One should say that about any field, which is one of the main points of this article). However, to say that computers are an "expensive, unproven technology" (p. 3) is misleading. Spending money on materials—and paper-based textbooks are a billion-dollar industry—that are too often not research-based and of questionable quality is an educational shame (including sales of left-over stock to the third world) (Clements, in press). However, this problem pertains to all technologies, and is a social, economic, and political situation that needs to be addressed globally. We suggest eschewing internal battles (adequate pay for teachers or adequate materials?) and working to provide children with the best of all research-based resources. Further, similar problems exist for many industries. Do the controversies regarding the pharmaceutical companies lead to calls for moratoriums on the use or creation of beneficial drugs? No, it is the culture that determines what and how various technologies are used. All educators should work toward a positive use of computers with children. Just spending money on computers without a plan will have a low probability of increasing achievement; however, spending a small bit in each classroom probably will not either. Large-scale, research-based model projects followed by planned implementation of successful models appears to be a wiser strategy. Finally, policy makers should realize that market forces alone would not provide high-quality content; new incentives are needed to fill noncommercial content and needs of all members of our society (Downes, Arthur, Beecher, & Kemp, 1999; Wartella & Jennings, 2000).

There is a need for human caring. Agreement on this issue is easy. *Fool's gold* repeatedly argues from this palpable foundation, but the reports' non-sequiturs frequently render its conclusions questionable or groundless. We will return to this point in a succeeding section.

THE WHOLE TRUTH (OR AT LEAST THE WHOLE STORY)

Thus, there are areas of agreement, and in a recent face-to-face discussion with one of the editors of *Fool's gold*, Edward Miller, we found conversation about concerns flowed easily. Our main objection is to the form and nature of the report itself. Our analysis of *Fool's gold's* treatment of

creativity was one stark example. In addition, *Fool's gold* describes the standard Piagetian line, ignoring most of what we have learned in the last few decades. Moreover, even standard Piagetian theory does not have the implications the report implies. As an example, Herb Ginsburg, co-author of one of the most popular Piagetian textbooks[14] (Ginsburg & Opper, 1979), is working with colleagues on a National Science Foundation (NSF)-sponsored mathematics curriculum for preschoolers, as are we on a separate project (Clements & Sarama, 1999). Both groups of researchers use Piagetian theory in research (Clements, 1984, 2000b; Clements et al., 1997) and curriculum development, but neither eschews mathematics experiences, including computer experiences, for young children. This is yet another example of *Fool's gold's* omission of any research contradicting their main points.

As another striking example, *Fool's gold* repeatedly quotes psychologist and sociologist Sherry Turkle to support it's positions, while ignoring her research reports that emphasize the learning, metacognitive gains, and the contagious spread of child-based knowledge that can occur within appropriate computer environments (Turkle, 1984, 1995, 1997). We asked Turkle about the way her work was cited, and she responded (personal communication, February 25, 2001) that she was quoted out of context and interpreted incorrectly. She stated that she believes (and we concur) that it is unwise to simply wire up schools instead of really thinking about the hard, and (often) expensive problems faced by education today. These issues have to do with social and economic problems as well as with appropriate pedagogy both with and without the computer presence. If computers are to be used, they must be used in a way that provides for meaningful educational and personal growth. This can be done but would be done more effective if the computer is not treated as an object that alone can produce positive change. It needs to be supported by a rich educational computer culture. This position, she insists, is very different from saying that the computer is not a powerful educational tool. She believes that it is. It simply is not an end unto itself. Further, Turkle's articles clearly state that computers can help children learn and should be used reflectively by both children and their teachers. Children should learn to understand how and why the programs they use work they way to do (Turkle, 1997).

Turkle further states that her research did not support the conclusions the *Fool's gold* authors implied that it did. For example, *Fool's gold* cited Turkle as supporting the statement that technology "is diverting attention from the urgent social and educational needs of low-income children." However,

Turkle told us that when she said these words she was arguing specifically against the mindless addition of computers to the classroom, without teacher training and planning. This is a very different statement. Turkle says she does not argue against computers, but does argue for thinking of computers in the context of a larger social, cultural, and economic picture. Turkle called other interpretations of her work in *Fool's gold* "biased" and "distorting of a research career that has tried to create a rich description of computers not just as an object that has an impact, but as part of a culture that is constructed in a particular social and psychological framework." The point, says Turkle, "is to create an educational computer culture that we can be proud of," not to turn our backs on this technology.

As another example, *Fool's gold* quotes the National Science Board:

> The fundamental dilemma of computer-based instruction and other Instructional Technology (IT)-based educational technologies is that their cost effectiveness compared to other forms of instruction—for example, smaller class sizes, self-paced learning, peer teaching, small group learning, innovative curricula, and in-class tutors—has never been proven. (p. 95)

However, they do not review other reports, such as one that concluded that computers may be as, or more, cost effective as other instructional interventions, such as peer tutoring and reducing class size (Niemiec & Walberg, 1987, note, however, we think the issue is still open and important, a topic to which we shall return). Further, they did not quote the National Science Board (1998) when that group reviewed studies that show, with pretraining, the effect size of computer-based instruction across many studies was 0.53, equivalent to one-half a school year gain, or 70th percentile performance. The Board concludes "meta-analyses of educational studies conducted between the late 1960s and the late 1980s consistently reveal positive impacts of computer-based instruction at the K-12 level" (and that "when the 'informationally disadvantaged' are given access to computers and the Internet, they use these resources effectively for self-empowerment," p. 8-3). In addition, they did not quote the Board stating "computer-based instruction can also be incorporated into enriched learning environments." For example, the Board cites one program for teaching economically disadvantaged students in the fourth through seventh grades, which resulted in double the national average gains on standardized tests in reading and mathematics (Costa & Liebmann, 1997). Two additional studies also suggest "the use of computers in enriched, nontraditional learning environments

might achieve the fundamental changes in student learning that advocates of computer-based instruction desire." These studies are above the age range of early childhood education that we have addressed. However, we should not leave this area without pointing out confirming research. As just one example, a recent national study found that computers could raise student achievement and even improve a school's climate (Education Week, 1998; Wenglinsky, 1998). At eighth grade, but not fourth, the use of drill and practice software was related to lower achievement. Instead, using computers to teach higher-order thinking with applications, simulations, and games raised achievement significantly.[15] Finally, the most recent report of the National Science Board (2000) concludes with a description of a review by Schacter:

> Collectively, these studies cover more than 700 empirical research studies and focus on the most recent work. On the basis of this review, Schacter (1999) concludes that "students with access to: (a) computer-assisted instruction or (b) integrated learning systems technology or (c) simulations and software that teach higher-order thinking or (d) collaborative networked technologies or (e) design and programming technologies show positive gains in achievements on research constructed tests, standardized tests, and national tests." Schacter also found evidence, however, that learning technology is less effective or ineffective when learning objectives are unclear and the purpose of the technology is unfocused (p. 9-25).

When the little research involving computers *Fool's gold* does include is cited at the end of a passage, the studies themselves usually have nothing to do with computers. For example, one passage warns against computer use:

> Because research findings across many scientific disciplines strongly suggests that later intellectual development is rooted in rich childhood experiences that combine healthy emotional relationships, physical engagement with the real world, and the exercise of imagination in self-generated play and in the arts. Intense use of computers can distract children and adults from these essential experiences.[17]

This footnote implies to the reader that this final point is documented by research. However, the long footnote merely provides justifications for a wide variety of experiences, including art, music, and physical education. There is no empirical evidence presented that computers distract people

from these experiences. (In contrast, we as well as others have presented evidence that computers can enrich children's developmental experiences.) Once again, this is misleading writing that does not contribute to the field or to children.

The major question is whether or not it is ever acceptable to tell half the story? To act is if everyone but the misinformed or profit seeking agrees with you? To proffer a portrait of only one side of a complicated research landscape? To consistently quote the opinions of a few "authorities"—those whose positions clearly support your position?[16] Even if it raises important concerns and foments discussion, this strategy may ultimately do more harm than good because it needlessly supports the widespread misconception that empirical studies in education do not develop reliable knowledge, thereby vitiating public confidence in such research. This furthers the cynicism and neglect that too often meets researchers' efforts to discuss educational issues with policymakers and with the public,[17] and threatens increased funding for research that is necessary in this field—there is a research corpus, but it is by no means complete.

FINAL WORDS

Fool's gold raises important issues and paints, in broad strokes, a picture of one view of children's development and learning. *Fool's gold*'s subtitle is: "A Critical Look at Computers in Childhood" We do need to look at computer use critically. By "critically," we mean, "Characterized by careful, exact evaluation and judgment." Another dictionary definition, one unfortunately favored by the authors and editors of *Fool's gold*, is "inclined to judge severely and find fault." They are more censorious than critical in an academic sense, and thus bring the fire of condemnation without adequate illumination.

In addition, their condemnations are of only certain technologies. Of thousands of years of the development of expressive technologies, the authors decided that time should be frozen at one narrow band. (Recall we discussed this issue regarding mathematics content and methodology.) Before there were brushes, paints, pencils, and paper, children probably interacted with, and represented, their natural world in different ways.[18] Was that better, or did the technologies of painting add to their development of their creativity and humanity? Our purpose is not to address these interesting questions in depth, but to illustrate that every technology may contribute to or attenuate depending on its affordances and applications. We argue

that there is little foundation for an a priori decision to expose children only to the technologies of a single era.

Consider first grader Darius, observed in a classroom-based study (St. Paul Public Schools, 1985). Darius never talked aloud, was slow to complete his work, and worked in a "socialization group" to "draw him out of his shell." When the computer arrived, Darius spent nearly 90 minutes with the machine his first day. Immediately thereafter, his teacher noticed that he was completing seatwork without prompting. Then he would slide his seat over to the computer and watch others program in Logo. Soon after, he would stand beside the computer, talking and making suggestions. When others had difficulties, he was quick to show them the solution. Others started getting help with Logo from him. In brief, Darius moved up from the lowest to the highest reading group. He began completing twice as much work per day as he had previously. He participated eagerly during class discussions and—as a "crowning achievement"—was given a 10 minute "time out" because he wouldn't stop talking (St. Paul Public Schools, 1985)!

Where is Darius in *Fool's gold*? Where are the hundreds of qualitative and quantitative studies that detail the potential benefits of appropriate computer use? Where are the children that have, are, and could benefit from such use? Buried under the avalanche of a one-sided diatribe.[19]

Misuse of technology by some and overzealous promotion by others are not valid reasons for misrepresenting the field or for speciously framing the computer as the lightning rod for a broad range of criticisms that can be reasonably attributed to no single source. This type of incomplete and dishonest reporting misdirects attention from the wider web of political and pedagogical concerns. It insults teachers who have found golden educational nuggets using computers by implying that they are fools. Articles such as Fools gold trammel the progress of research and expert practice that can guide developmentally appropriate and beneficial use of computers. Finally violence tis committed to the academic enterprise by reinforcing the cynical belief that research can also support either of polar opposite opinions.

The bottom line regarding computers in education is this: We know materials and media are frequently misused or used ineffectively in education. Let us not call for a technological prohibition, especially one built on a specious foundation that ignores the hundreds of studies and reviews that contradict such a position. Instead, let us work together to use technology well.[20]

When we discuss when and how technology should and should not be used, let us be honest both academically and politically, eschewing the most base techniques of advertisers and embodying and modeling rational discourse considering all available evidence.

Although we hope to correct misconceptions about computers in education, this is not the main force of our argument We are concerned with the need for complete, balanced, consideration and reporting of research. A recent plea for raising the standards of reporting and interpretation of educational research—"because findings can quickly become distorted or misinterpreted and enshrined through misinformed policy decisions" (Taylor, Anderson, Au, & Raphael, 2000, p. 16)—addressed the dissemination of research findings before complete peer review. The creators of *Fool's gold* sought significant media attention although it was never intended to be peer reviewed. Nor did it consist of a complete, competent review of the most specifically relevant body of research. Even more frustrating from an academic perspective, it received "stamps of approval" from several researchers who signed the report. This type of polemic promulgates a jeremiad in the masquerade of academic respectability. It undermines the profession as well as the body of accumulated knowledge from research and the wisdom of expert practice that we believe is one essential cultural contribution to the welfare of children.

References

Alchin, G. (1993). Increasing self esteem and creativity of people with a developmental disability through the use of computer technology. *Australian Educational Computing, 8*, 19-24.

Alexander, D. (1984). Mathematical, geometric and spatial reasoning. In E.G. Pitcher, S.G. Feinburg, & D. Alexander (Eds.), *Helping young children learn (4th ed.)* (pp. 185-207). Columbus, OH: Charles E. Merrill.

Allen, J., Watson, J.A., & Howard, J.R. (1993). The impact of cognitive styles on the problem solving strategies used by preschool minority children in Logo microworlds. *Journal of Computing in Childhood Education, 4*, 203-217.

American Academy of Pediatrics. (1999). Media education. *Pediatrics, 104*, 341-343.

Anderson, G.T. (2000). *An empirical comparison of the proportion of cooperative play of 4-year-old preschool children observed as they interact in four centers: block, computer, housekeeping, and manipulative*. Atlanta, GA:

National Association for the Education of Young Children.
Bangert-Drowns, R.L. (1989). *Research on word processing and writing instruction*. San Francisco: American Educational Research Association.
Bangert-Drowns, R.L. (1993). The word processor as an instructional tool: A meta-analysis of word processing in writing instruction. *Review of Educational Research, 63*(1), 69-93.
Barnes, B.J., & Hill, S. (1983, May). Should young children work with microcomputers—Logo before Lego™ *The Computing Teacher, 10,* 11-14.
Becker, H.J. (1990). How computers are used in United States schools: Basic data from the 1989 I.E.A. Computers in Education Survey. *Journal of Educational Computing Research, 7,* 385-406.
Becker, H.J. (1994). *Analysis and trends of school use of new information technologies*: Unpublished manuscript, Dept. of Education, University of California, Irvine.
Becker, H.J. (2000). Who's wired and who's not: Children's access to and use of computer technology. *The Future of Children, 10*(2), 44-75.
Behrmann, R.E. (2000). Children and computer technology [Special issue]. *The Future of Children, 10*(2).
Bergin, D., Ford, M.E., & Meyer-Gaub, B. (1986). *Social and motivational consequences of microcomputer use in kindergarten*. San Francisco, CA: American Educational Research Association.
Bergin, D.A., Ford, M.E., & Hess, R.D. (1993). Patterns of motivation and social behavior associated with microcomputer use of young children. *Journal of Educational Psychology, 85,* 437-445.
Bernhard, J.K., & Siegel, L.S. (1994). Increasing internal locus of control for a disadvantaged group: A computer intervention. *Computers in the Schools, 11*(1), 59-77.
Binder, S.L., & Ledger, B. (1985). *Preschool computer project report*. Oakville, Ontario, Canada: Sheridan College.
Blanton, W.E., Moorman, G.B., Hayes, B.A., & Warner, M.L. (2000). *Effects of participation in the Fifth Dimension on far transfer*. Boone, NC: Laboratory on Technology and Learning, Appalacian State University, College of Education.
Bowman, B.T. (1985). *Computers and young children*. New Orleans: National Association for the Education of Young Children.
Bowman, B.T., Donovan, M.S., & Burns, M.S. (Eds.). (2001). *Eager to learn: Educating our preschoolers*. Washington, DC: National Academy Press.
Bradley, V. N. (1982). Improving students' writing with microcomputers. *Language Arts, 59*(7), 732-743.
Brinkley, V. M., & Watson, J. A. (1987-88a). Effects of microworld training experience on sorting tasks by young children. *Journal of Educational Technology Systems, 16,* 349-364.
Brinkley, V.M., & Watson, J.A. (1987-88b). Logo and young children: Are quadrant effects part of initial Logo mastery? *Journal of Educational Tech-*

nology Systems, 19, 75-86.

Browning, C.A. (1991). Reflections on using Lego®TC Logo in an elementary classroom. In E. Calabrese (Ed.), *Proceedings of the Third European Logo Conference* (pp. 173-185). Parma, Italy: Associazione Scuola e Informatica.

Campbell, P.F. (1987). *Measuring distance: Children's use of number and unit.* Final report submitted to the National Institute of Mental Health Under the ADAMHA Small Grant Award Program. Grant No. MSMA 1 R03 MH423435-01. College Park, MD: University of Maryland, College Park.

Campione, J.C., Brown, A.L., & Jay, M. (1992). Computers in a community of learners. In E. De Corte, M. C. Linn, H. Mandl, & L. Verschaffel (Eds.), *Computer-based learning environments and problem solving* (pp. 163-188). New York: Springer-Verlag.

Carmichael, H.W., Burnett, J.D., Higginson, W.C., Moore, B.G., & Pollard, P.J. (1985). *Computers, children and classrooms: A multisite evaluation of the creative use of microcomputers by elementary school children*. Toronto, Ontario, Canada: Ministry of Education.

Chang, L.L., & Osguthorpe, R.T. (1990). The effects of computerized picture-word processing on kindergartners' language development. *Journal of Research in Childhood Education, 5*, 73-84.

Char, C.A. (1989). *Computer graphic feltboards: New software approaches for young children's mathematical exploration*. San Francisco: American Educational Research Association.

Childers, R.D. (Cartographer). (1989). *Implementation of the Writing to Read instructional system in 13 rural elementary schools in southern West Virginia. 1988-89 annual report*. Charleston, WV: Appalachia Educational Library.

Clements, D.H. (1984). Training effects on the development and generalization of Piagetian logical operations and knowledge of number. *Journal of Educational Psychology, 76*, 766-776.

Clements, D.H. (1985). Technological advances and the young child: Television and computers. In C. S. Mcloughlin & D. F. Gullo (Eds.), *Young children in context: Impact of self, family and society on development* (pp. 218-253). Springfield, IL: Charles Thomas.

Clements, D.H. (1986). Effects of Logo and CAI environments on cognition and creativity. *Journal of Educational Psychology, 78*, 309-318.

Clements, D.H. (1987a). Computers and literacy. In J. L. Vacca, R. T. Vacca, & M. Gove (Eds.), *Reading and learning to read* (pp. 338-372). Boston: Little, Brown.

Clements, D.H. (1987b). Longitudinal study of the effects of Logo programming on cognitive abilities and achievement. *Journal of Educational Computing Research, 3*, 73-94.

Clements, D.H. (1989). *Computers in elementary mathematics education*. Englewood Cliffs, NJ: Prentice-Hall.

Clements, D.H. (1991). Enhancement of creativity in computer environments.

American Educational Research Journal, 28, 173-187.
Clements, D.H. (1993). Computer technology and early childhood education. In J. L. Roopnarine & J. E. Johnson (Eds.), *Approaches to early childhood education* (2nd ed.), pp. 295-316. New York: Merrill.
Clements, D.H. (1994). The uniqueness of the computer as a learning tool: Insights from research and practice. In J. L. Wright & D. D. Shade (Eds.), *Young children: Active learners in a technological age* (pp. 31-50). Washington, DC: National Association for the Education of Young Children.
Clements, D.H. (1995a). Playing with computers, playing with ideas. *Educational Psychology Review, 7*(2), 203-207.
Clements, D.H. (1995b). Teaching creativity with computers. *Educational Psychology Review, 7*(2), 141-161.
Clements, D.H. (1999). Concrete manipulatives, concrete ideas. *Contemporary Issues in Early Childhood, 1*(1), 45-60.
Clements, D.H. (2000a). From exercises and tasks to problems and projects: Unique contributions of computers to innovative mathematics education. *Journal of Mathematical Behavior, 19*, 9-47.
Clements, D.H. (2000b). *Geometric and spatial thinking in early childhood education*. San Francisco, CA: Research Presession: The 78th annual meeting of the National Council of Teachers of Mathematics.
Clements, D.H. (in press). Linking research and curriculum development. In L.D. English (Ed.), *Handbook of International Research in Mathematics Education*. Mahwah, NJ: Lawrence Erlbaum.
Clements, D.H., & Battista, M.T. (1989). Learning of geometric concepts in a Logo environment. *Journal for Research in Mathematics Education, 20*, 450-467.
Clements, D.H., & Battista, M T. (in press). *Logo and geometry*. Reston, VA: National Council of Teachers of Mathematics.
Clements, D.H., Battista, M.T., Sarama, J., & Swaminathan, S. (1996). Development of turn and turn measurement concepts in a computer-based instructional unit. *Educational Studies in Mathematics, 30*, 313-337.
Clements, D.H., Battista, M.T., Sarama, J., Swaminathan, S., & McMillen, S. (1997). Students' development of length measurement concepts in a Logo-based unit on geometric paths. *Journal for Research in Mathematics Education, 28*(1), 70-95.
Clements, D.H., & Burns, B.A. (2000). Students' development of strategies for turn and angle measure. *Educational Studies in Mathematics, 41*, 31-45.
Clements, D. H., & Gullo, D.F. (1984). Effects of computer programming on young children's cognition. *Journal of Educational Psychology, 76*, 1051-1058.
Clements, D.H., & McMillen, S. (1996). Rethinking "concrete" manipulatives. *Teaching Children Mathematics, 2*(5), 270-279.
Clements, D.H., & Nastasi, B. K. (1985). Effects of computer environments on social-emotional development: Logo and computer-assisted instruction.

Computers in the Schools, 2(2-3), 11-31.

Clements, D.H., & Nastasi, B.K. (1992). Computers and early childhood education. In M. Gettinger, S.N. Elliott, & T.R. Kratochwill (Eds.), *Advances in school psychology: Preschool and early childhood treatment directions* (pp. 187-246). Hillsdale, NJ: Lawrence Erlbaum.

Clements, D.H., & Nastasi, B.K. (1993). Electronic media and early childhood education. In B. Spodek (Ed.), *Handbook of research on the education of young children* (pp. 251-275). New York: Macmillan.

Clements, D.H., Nastasi, B.K., & Swaminathan, S. (1993). Young children and computers: Crossroads and directions from research. *Young Children, 48*(2), 56-64.

Clements, D.H., & Sarama, J. (1997). Research on Logo: A decade of progress. *Computers in the Schools, 14*(1-2), 9-46.

Clements, D.H., & Sarama, J. (1998). *Building blocks—Foundations for mathematical thinking, pre-kindergarten to grade 2: Research-based materials development* [National Science Foundation, grant number ESI-9730804; Buffalo, NY: State University of New York at Buffalo [Online]. Available: www.gse.buffalo.edu/org/buildingblocks/

Clements, D.H., & Sarama, J. (1999). *Preliminary report of building blocks—Foundations for mathematical thinking, pre-kindergarten to grade 2: Research-based Materials Development* (NSF Grant No. ESI-9730804). Buffalo, NY: State University of New York at Buffalo.

Clements, D.H., & Sarama, J. (in press). Learning and teaching with computers in early childhood education. In B. Spodek (Ed.), *Contemporary Perspectives in Early Childhood Education*. Greenwich, CT: Information Age.

Clements, D.H., Sarama, J., & DiBiase, A.M. (Eds.) (in press). *Engaging young children in mathematics: Standards for early childhood mathematics education*. Mahwah, NJ: Lawrence Erlbaum.

Clements, D. H., & Swaminathan, S. (1995). Technology and school change: New lamps for old? *Childhood Education, 71*, 275-281.

Cochran-Smith, M., Kahn, J., & Paris, C. L. (1988). When word processors come into the classroom. In J. L. Hoot & S. B. Silvern (Eds.), *Writing with computers in the early grades* (pp. 43-74). New York: Teachers College Press.

Cognition and Technology Group at Vanderbilt. (1998). Designing environments to reveal, support, and expand our children's potentials. In S. Soraci & W. J. McIlvane (Eds.), *Perspectives on fundamental processes in intellectual functioning: Volume 1—A survey of research approaches* (pp. 313-350). Stamford, CT: Ablex.

Cohen, R., & Geva, E. (1989). Designing Logo-like environments for young children: The interaction between theory and practice. *Journal of Educational Computing Research, 5*, 349-377.

Cordes, C., & Miller, E. (2000). *Fool's gold: A critical look at computers in childhood*. Alliance for Childhood. Retrieved November 7, 2000, from: http://www.allianceforchildhood.net/projects/computers/

computers_reports.htm
Cosden, M.A. (1988). Microcomputer instruction and perceptions of effectiveness by special and regular education elementary teachers. *The Journal of Special Education, 22*, 242-253.
Costa, A.L., & Liebmann, R.M. (Eds.). (1997). *Supporting the spirit of learning: When process is content*. Thousand Oaks, CA: Corwin Press.
Cuban, L. (2001). *Oversold and underused*. Cambridge, MA: Harvard University Press.
Cunningham, A.E., & Stanovich, K.E. (1990). Early spelling acquisition: Writing beats the computer. *Journal of Educational Psychology, 82*, 159-162.
Daiute, C. (1988). The early development of writing abilities: Two theoretical perspectives. In J.L. Hoot & S.B. Silvern (Eds.), *Writing with computers in the early grades* (pp. 10-22). New York: Teachers College Press.
Dewey, J. (1963). *Experience and education*. New York: Collier Books.
Dickinson, D.K. (1986). Cooperation, collaboration, and a computer: Integrating a computer into a first-second grade writing program. *Research in the Teaching of English, 20*, 357-378.
Doran, L.A., & Kalinowski, M.F. (1991). Reducing adult computer anxiety: Lessons from preschool child tutors. *Journal of Computing in Childhood Education, 2*(3), 41-50.
Downes, T., Arthur, L., Beecher, B., & Kemp, L. (1999). *Appropriate EdNA services for children eight years and younger*. University of Western Sydney, Macarthur. Report commissioned by Education.AU Limited for the EdNA Online Pathways Project.
du Boulay, B. (1986). Part II: Logo confessions. In R. Lawler, B. du Boulay, M. Hughes, & H. Macleod (Eds.), *Cognition and computers: Studies in learning* (pp. 81-178). Chichester, England: Ellis Horwood Limited.
Education Week. (1998, October 1, 1998). *Technology counts '98* [Online]. Available: http://www.edweek.org/sreports/tc98/tchome.htm
Elkind, D. (1987, May). The child yesterday, today, and tomorrow. *Young Children*, 6-11.
Elkind, D. (1998). Computers for infants and young children. *Child Care Information Exchange, 123*, 44-46.
Elliott, A. (1993). Effects of gender on preschoolers' play and learning in Logo environments. *Journal of Computing in Childhood Education, 4*, 103-124.
Emihovich, C., & Miller, G. E. (1988). Talking to the turtle: A discourse analysis of Logo instruction. *Discourse Processes, 11*, 183-201.
Enkenberg, J. (1994). Situated programming in a LEGOLogo environment. *Computers and Education, 22*(1-2), 119-128.
Escobedo, T.H. (1992). Play in a new medium: Children's talk and graphics at computers. *Play and Culture, 5*, 120-140.
Fatouros, C. (1995). Young children using computers: Planning appropriate learning experiences. *Australian Journal of Early Childhood, 20*(2), 1-6.
Fisher, C.W. (1990/1991). Some influences of classroom computers on academic tasks. *Journal of Computing in Childhood Education, 2*, 3-15.
Flake, J.L. (1990). An exploratory study of Lego Logo. *Journal of Computing*

in Childhood Education, 1(3), 15-22.
Fletcher, J.D., Hawley, D.E., & Piele, P.K. (1990). Costs, effects, and utility of microcomputer assisted instruction in the classroom. *American Educational Research Journal, 27*, 755-782.
Fletcher-Flinn, C.M., & Gravatt, B. (1995). The efficacy of computer assisted introduction (CAI): A meta-analysis. *Journal of Educational Computing Research, 12*, 219-242.
Forman, G. (1985). *The child's understanding of record and replay in computer animated graphics*. Chicago, IL: American Educational Research Association.
Forman, G. (1986). Computer graphics as a medium for enhancing reflective thinking in young children. In J. Bishop, J. Lochhead, & D. N. Perkins (Eds.), *Thinking* (pp. 131-137). Hillsdale, NJ: Lawrence Erlbaum.
Foster, K.C., Erickson, G.C., Foster, D.F., Brinkman, D., & Torgesen, J.K. (1994). Computer administered instruction in phonological awareness: Evaluation of the DaisyQuest program. *Journal of Research and Development in Education, 27*, 126-137.
Fowler, C. (1988). *Can we rescue the arts for America's children*. New York: American Council for the Arts.
Frazier, M.K. (1987). *The effects of Logo on angle estimation skills of 7th graders*. Unpublished master's thesis, Wichita State University.
Garaigordobil, M., & Echebarria, A. (1995). Assessment of a peer-helping game program on children's development. *Journal of Research in Childhood Education, 10*, 63-69.
Gardner, C. M., Simmons, P. E., & Simmons, R. D. (1992). The effects of CAI and hands-on activities on elementary students' attitudes and weather knowledge. *School Science and Mathematics, 92*, 334-336.
Gardner, H. (1983). *Frames of mind: The theory of multiple intelligences*. New York: Basic Books.
Gelman, R., & Baillargeon, R. (1983). A review of some Piagetian concepts. In P. H. Mussen (Ed.), *Handbook of child psychology* (4th ed., Vol. 3, pp. 167-230). New York: John Wiley & Sons.
Gelman, R., & Williams, E.M. (1997). Enabling constraints for cognitive development and learning: Domain specificity and epigenesis. In D. Kuhn & R. Siegler (Eds.), *Cognition, perception, and language. Volume 2: Handbook of Child Psychology* (Fifth ed., pp. 575-630). New York: John Wiley & Sons.
Genishi, C., McCollum, P., & Strand, E. B. (1985). Research currents: The interactional richness of children's computer use. *Language Arts, 62*(5), 526-532.
Ginsburg, H., & Opper, S. (1979). *Piaget's theory of intellectual development* (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.
Goodwin, L.D., Goodwin, W.L., & Garel, M.B. (1986). Use of microcomputers with preschoolers: A review of the literature. *Early Childhood Research Quarterly, 1*, 269-286.
Goodwin, L.D., Goodwin, W.L., Nansel, A., & Helm, C.P. (1986). Cognitive and affective effects of various types of microcomputer use by preschool-

ers. *American Educational Research Journal, 23*, 348-356.
Gore, D.A., Morrison, G.N., Maas, M.L., & Anderson, E.A. (1989). A study of teaching reading skills to the young child using microcomputer assisted instruction. *Journal of Educational Computing Research, 5*, 179-185.
Graybill, D., Kirsch, J.R., & Esselman, E.D. (1985). Effects of playing violent vs. nonviolent video games on the aggressive ideation of aggressive and nonaggressive children. *Child Study Journal, 15*, 199-205.
Green, L.C. (1991). The effects of word processing and a process approach to writing on the reading and writing achievement, revision and editing strategies, and attitudes towards writing of third-grade Mexican-American students, *Dissertation Abstracts International 52-12,* 4245.
Gustafsson, K., Mellgren, E., Klerfelt, A., & Samuelsson, I.P. (1999). *Preschool teachers—Children, computers, and IT: An exploratory study*. Gothenburg, Sweden: EARLI 99: The 8th European Conference for Research and Learning.
Haugland, S.W. (1992). Effects of computer software on preschool children's developmental gains. *Journal of Computing in Childhood Education, 3*(1), 15-30.
Hawisher, G.E. (1989). Research and recommendations for computers and composition. In G. E. Hawisher & C. L. Selfe (Eds.), *Critical perspectives on computers and composition instruction* (pp. 44-69). New York: Teachers College Press.
Hess, R.D., & McGarvey, L. (1987). School-relevant effects of educational uses of microcomputers in kindergarten classrooms and homes. *Journal of Educational Computing Research, 3*, 269-287.
Hiebert, J.C. (1999). Relationships between research and the NCTM Standards. *Journal for Research in Mathematics Education, 30*, 3-19.
Hine, M.S., Goldman, S.R., & Cosden, M.A. (1990). Error monitoring by learning handicapped students engaged in collaborative microcomputer-based writing. *The Journal of Special Education, 23*(4), 407-422.
Hlawati, B. (1985). *Effects of Logo and problem-solving CAI on the cognitive processes of gifted children.* Unpublished doctoral dissertation, Kent State University.
Holmes, D.J., & Godlewski, J.B. (1995). *The attitude toward writing of first grade students using computers with the help of peer coaches.* Paper presented at the The Twelfth International Conference on Technology and Education, Orlando, FL.
Hoover, J.M., & Austin, A.M. (1986). *A comparison of traditional preschool and computer play from a social/cognitive perspective*. San Francisco, CA: American Educational Research Association.
Horton, J., & Ryba, K. (1986). Assessing learning with Logo: A pilot study. *The Computing Teacher, 14*(1), 24-28.
Howard, J., Greyrose, E., Kehr, K., Espinosa, M., & Beckwith, L. (1996). Teacher-facilitated microcomputer activities: Enhancing social play and affect in young children with disabilities. *Journal of Special Education Tech-*

nology, 13, 36-47.
Howard, J.R., Watson, J.A., & Allen, J. (1993). Cognitive style and the selection of Logo problem-solving strategies by young black children. *Journal of Educational Computing Research, 9*, 339-354.
Howland, J., Laffey, J., & Espinosa, L.M. (1997). A computing experience to motivate children to complex performances. *Journal of Computing in Childhood Education, 8*, 291-311.
Hungate, H. (1982, January). Computers in the kindergarten. *The Computing Teacher, 9*, 15-18.
Hutinger, P.L., Bell, C., Beard, M., Bond, J., Johanson, J., & Terry, C. (Cartographer). (1998). *The early childhood emergent literacy technology research study. Final report.*
Hutinger, P.L., & Johanson, J. (2000). Implementing and maintaining an effective early childhood comprehensive technology system. *Topics in Early Childhood Special Education, 20*(3), 159-173.
Ishigaki, E.H., Chiba, T., & Matsuda, S. (1996). Young children's communication and self expression in the technological era. *Early Childhood Development and Care, 119*, 101-117.
Israel, B.L. (Cartographer). (1968). *The talking typewriter, responsive environment program: Brooklyn, NY.* Report of the first full year of operation.
Jones, I. (1998). The effect of computer-generated spoken feedback on kindergarten students' written narratives. *Journal of Computing in Childhood Education, 9*(1), 43-56.
Jones, I., & Pellegrini, A.D. (1996). The effect of social relationships, writing media, and microgenetic development on first-grade students' written narratives. *American Educational Research Journal, 33*, 691-718.
Karmiloff-Smith, A. (1990). Constraints on representational change: Evidence from children's drawing. *Cognition, 34*, 57-83.
Kelly, A.E., & O'Kelly, J.B. (1994). Extending a tradition: Teacher designed computer-based games. *Journal of Computing in Childhood Education, 5*, 153-166.
Kent, J.F., & Rakestraw, J. (1994). The role of computers in functional language: A tale of two writers. *Journal of Computing in Childhood Education, 5*(3/4), 329-337.
Kieran, C. (1986). Logo and the notion of angle among fourth and sixth grade children. In C. Hoyles & L. Burton (Eds.), *Proceedings of the Tenth Annual Meeting of the International Group for the Psychology in Mathematics Education* (pp. 99-104). London, England: City University.
Kieran, C., & Hillel, J. (1990). It's tough when you have to make the triangles angles: Insights from a computer-based geometry environment. *Journal of Mathematical Behavior, 9*, 99-127.
King, J.A., & Alloway, N. (1992). Preschooler's use of microcomputers and input devices. *Journal of Educational Computing Research, 8*, 451-468.
Klinzing, D.G., & Hall, A. (1985). *A study of the behavior of children in a preschool equipped with computers*. Chicago, IL: American Educational Re-

search Association.
Kokish, R. (1994). Experiences using a PC in play therapy with children. *Computers in Human Services, 11*(1-2), 141-150.
Kraut, R., Patterson, M., Lundmark, V., Kiesler, S., Mukopadhyay, T., & Scherlis, W. (1998). Internet paradox: A social technology that reduces social involvement and psychological well-being. *American Psychologist, 53*, 1017-1031.
Kromhout, O.M., & Butzin, S.M. (1993). Integrating computers into the elementary school curriculum: An evaluation of nine Project CHILD model schools. *Journal of Research on Computing in Education, 26*(1), 55-69.
Kull, J.A. (1986). Learning and Logo. In P.F. Campbell & G.G. Fein (Eds.), *Young children and microcomputers* (pp. 103-130). Englewood Cliffs, NJ: Prentice-Hall.
Kurth, R.J. (1987, January). Using word processing to enhance revision strategies during student writing activities. *Educational Technology, 27,* 13-19.
Kurth, R.J. (1988). *Process variables in writing instruction using word processing, word processing with voice synthesis, and no word processing*. New Orleans: American Educational Research Association.
Kurth, R.J., & Kurth, L.M. (1987). *A comparison of writing instruction using and word processing, word processing with voice synthesis, and no word processing in kindergarten and first grade*. Washington, DC: American Educational Research Association.
Lafer, S., & Markert, A. (1994). Authentic learning situations and the potential of Lego TC Logo. *Computers in the Schools, 11*(1), 79-94.
Lai, K.W. (1993). Lego-Logo as a learning environment. *Journal of Computing in Childhood Education, 4*, 229-245.
Lavin, R., & Sanders, J. (1983). *Longitudinal evaluation of the C/A/I Computer Assisted Instruction Title 1 Project: 1979-1982*. Chelmsford, MA: Merrimack Education Center.
Lehrer, R., & deBernard, A. (1987). Language of learning and language of computing: The perceptual-language model. *Journal of Educational Psychology, 79*, 41-48.
Lehrer, R., Levin, B.B., DeHart, P., & Comeaux, M. (1987). Voice-feedback as a scaffold for writing: A comparative study. *Journal of Educational Computing Research, 3*, 335-353.
Lesh, R.A., & Lesh, J. (1989). On-the-job teacher education. In I. Wirszup & R. Streit (Eds.), *Developments in school mathematics education around the world*. Reston, VA: National Council of Teachers of Mathematics.
Lewin, C. (1997). "Test driving" CARS: Addressing the issues in the evaluation of computer-assisted reading software. *Journal of Computing in Childhood Education, 8*(2/3), 111-132.
Lin, S., Vallone, R.P., & Lepper, M.R. (1985). *Teaching early reading skills: Can computers help?* San Jose, CA: Western Psychological Association.
Lipinski, J.M., Nida, R.E., Shade, D.D., & Watson, J.A. (1986). The effects of microcomputers on young children: An examination of free–play choices, sex differences, and social interactions. *Journal of Educational Computing*

Research, 2, 147-168.
Lukens, D.C. (1984). A compass-and-computer perspective on technology. In V. P. Hansen & M. J. Zweng (Eds.), *Computers in mathematics education (1984 Yearbook)* (pp. 15-19). Reston, VA: National Council of Teachers of Mathematics.
Malone, T.W. (1980). What make things fun to learn? A study of intrinsically motivating computer games, *Dissertation Abstracts International, 41*, 1955B.
Matthew, K. (1997). A comparison of the influence of interactive CD-ROM storybooks and traditional print storybooks on reading comprehension. *Journal of Research on Computing in Education, 29*, 263-275.
McCauley, J. (1983-84, December/January). Kepler. *The Computing Teacher*, 15-22.
McCormick, L. (1987). Comparison of the effects of a microcomputer activity and toy play on social and communication behaviors of young children. *Journal of the Division for Early Childhood, 11*, 195-205.
McKenna, M.C. (1998). Electronic texts and the transformation of beginning reading. In D. Reinking & M. C. McKenna & L. D. Labbo & R. D. Kieffer (Eds.), *Handbook of literacy and technology* (pp. 45-59). Mahwah, NJ: Lawrence Erlbaum.
Mehan, H. (1989). Microcomputers in classrooms: Educational technology or social practice? *Anthropology & Education Quarterly, 20*, 4-22.
Mikropoulos, T.A., Kossivaki, P., Katsikis, A., & Savranides, C. (1994). Computers in preschool education: An interactive environment. *Journal of Computing in Childhood Education, 5*, 339-351.
Mitterer, J., & Rose-Drasnor, L. (1986). LOGO and the transfer of problem solving: An empirical test. *The Alberta Journal of Educational Research, 32*, 176-194.
Moxley, R.A., Warash, B., Coffman, G., Brinton, K., & Concannon, K. R. (1997). Writing development using computers in a class of three-year-olds. *Journal of Computing in Childhood Education, 8*(2/3), 133-164.
Muhlstein, E.A., & Croft, D.J. (Cartographer). (1986). *Using the microcomputer to enhance language experiences and the development of cooperative play among preschool children.* Cupertino, CA: DeAnza College
Muller, A.A., & Perlmutter, M. (1985). Preschool children's problem-solving interactions at computers and jigsaw puzzles. *Journal of Applied Developmental Psychology, 6*, 173-186.
Murphy, R.T., & Appel, L.R. (1984). *Evaluation of writing to read*. Princeton, NJ: Educational Testing Service.
Nastasi, B.K., & Clements, D.H. (1993). Motivational and social outcomes of cooperative education environments. *Journal of Computing in Childhood Education, 4*(1), 15-43.
Nastasi, B.K., & Clements, D.H. (1994). Effectance motivation, perceived scholastic competence, and higher-order thinking in two cooperative computer environments. *Journal of Educational Computing Research, 10*, 249-275.
Nastasi, B.K., Clements, D.H., & Battista, M.T. (1990). Social-cognitive interactions, motivation, and cognitive growth in Logo programming and CAI problem-solving environments. *Journal of Educational Psychology, 82*,

150-158.
National Association for the Education of Young Children and the International Reading Association. (1998, July). Learning to read and write: Developmentally appropriate practices for young children. *Young Children*, 30-46.
National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. Reston, VA: Author.
National Science Board. (1998). *Science & Engineering Indicators – 1998 (NSB 98-l)*. Arlington, VA: National Science Foundation.
National Science Board. (2000). *Science & Engineering Indicators – 2000 (NSB-00-1)*. Arlington, VA: National Science Foundation.
NCTM. (2000). *Principles and standards for school mathematics*. Reston, VA: National Council of Teachers of Mathematics.
Neufeld, K. (1989). When children use word processors for writing: Some problems and suggestions. *Reading Improvement, 26*(1), 64-70.
Niemiec, R., & Walberg, H.J. (1987). Comparative effects of computer-assisted instruction: A synthesis of reviews. *Journal of Educational Computing Research, 3*, 19-37.
Niemiec, R.P., & Walberg, H.J. (1984). Computers and achievement in the elementary schools. *Journal of Educational Computing Research, 1*, 435-440.
Oken-Wright, P. (1999). The technological languages of young children. *Focus on Pre-K & K, 12*(2), 1-3, 6.
Okolo, C.M. (1991). Learning and behaviorally handicapped students' perceptions of instructional and motivational features of computer assisted instruction. *Journal of Research on Computing in Education, 24*(2), 171-188.
Olive, J., Lankenau, C.A., & Scally, S.P. (1986). *Teaching and understanding geometric relationships through Logo: Phase II*. Interim Report: The Atlanta–Emory Logo Project. Altanta, GA: Emory University.
Olson, J.K. (1988). *Microcomputers make manipulatives meaningful*. Budapest, Hungary: International Congress of Mathematics Education.
Orleans, M., & Laney, M. C. (2000). Children's computer use in the home. *Social Science Computer Review, 18*, 56-72.
Owston, R.D., & Wideman, H.H. (1997). Word processors and children's writing in a high-computer-access setting. *Journal of Research on Computing in Education, 30*, 202-220.
Palmer, S. (1993). Does computer use put children's vision at risk? *Journal of Research and Development in Education, 26*, 59-65.
Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York: Basic Books.
Papert, S. (1985). Computer criticism vs. technocentric thinking, *Logo 85 Theoretical Papers* (pp. 53-67). Cambridge, MA: Massachusetts Institute of Technology.
Papert, S. (1998). Let's tie the digital knot. *TECHNOS Quarterly for Education and Technology, 7*(4).
Perlmutter, M., Behrend, S., Kuo, F., & Muller, A. (1986). *Social influence on children's problem solving at a computer*: Unpublished manuscript, Uni-

versity of Michigan, Ann Arbor.
Phenix, J., & Hannan, E. (1984). Word processing in the grade one classroom. *Language Arts, 61*, 804-812.
Piaget, J., & Inhelder, B. (1967). *The child's conception of space*. New York: W.W. Norton.
Picard, A.J., & Giuli, C. (1985). *Computers as a free–time activity in grades K-4: A two year study of attitudes and usage*: Unpublished manuscript, University of Hawaii, Honolulu, HI.
Plourde, R.R. (1987, December). The insignificance of Logo—Stop "mucking around" with computers. *Micro-Scope,* 30-31.
President's Committee of Advisors on Science and Technology—Panel on Educational Technology. (1997). *Report to the president on the use of technology to strengthen K-12 education in the United States.* Washington, DC: Author.
Ragosta, M., Holland, P., & Jamison, D.T. (1981). *Computer-assisted instruction and compensatory education: The ETS/LAUSD study*. Princeton, NJ: Educational Testing Service.
Reed, W.M. (1996). Assessing the importance of computer-based writing instruction. *Journal of Research on Computing in Education, 28*, 418-437.
Reimer, G. (1985). Effects of a Logo computer programming experience on readiness for first grade, creativity, and self concept. "A pilot study in kindergarten". *AEDS Monitor, 23*(7-8), 8-12.
Resnick, M. (1988). LEGO, Logo, and design. *Children's Environments Quarterly, 5*(4), 14-18.
Rhee, M.C., & Bhavnagri, N. (Cartographer). (1991). *Four year old children's peer interactions when playing with a computer.* Detroit, MI: Wayne State University. (ERIC Document Reproduction Service No. ED 342 466)
Riding, R.J., & Tite, H.C. (1985). The use of computer graphics to facilitate story telling in young children. *Educational Studies, 11*, 203-210.
Riel, M. (1994). Educational change in a technology-rich environment. *Journal of Research on Computing in Education, 26*(4), 452-474.
Robinson, M.A., Gilley, W.F., & Uhlig, G.E. (1988). The effects of guided discovery Logo on SAT performance of first grade students. *Education, 109*, 226-230.
Robinson, M. A., & Uhlig, G. E. (1988). The effects of guided discovery Logo instruction on mathematical readiness and visual motor development in first grade students. *Journal of Human Behavior and Learning, 5*, 1-13.
Roblyer, M. D., Castine, W. H., & King, F. J. (1988). *Assessing the impact of computer-based instruction: A review of recent research*. New York: Haworth Press.
Rosegrant, T.J. (1988). Talking word processors for the early grades. In J.L. Hoot & S.B. Silvern (Eds.), *Writing with computers in the early grades* (pp. 143-159). New York: Teachers College Press.
Rosengren, K.S., Gross, D., Abrams, A.F., & Perlmutter, M. (1985). *An observational study of preschool children's computing activity*. Austin, TX: "Perspectives on the Young Child and the Computer" conference, Univer-

sity of Texas at Austin.
Ross, J.A., Hogaboam-Gray, A., & Hannay, L. (2001). *Collateral benefits of an interactive literacy program for grade 1 and 2 students*. Paper presented at the Annual Meeting of the American Educational Research Association, Montreal, Quebec, Canada, April 19-23, 1999.
Sarama, J. (1995). *Redesigning Logo: The turtle metaphor in mathematics education*. Unpublished doctoral dissertation, State University of New York at Buffalo.
Sarama, J. (2000). Toward more powerful computer environments: Developing mathematics software on research-based principles. *Focus on Learning Problems in Mathematics, 22*(3&4), 125-147.
Sarama, J., Clements, D.H., & Henry, J.J. (1998). Network of influences in an implementation of a mathematics curriculum innovation. *International Journal of Computers for Mathematical Learning, 3*, 113-148.
Sarama, J., Clements, D.H., & Vukelic, E.B. (1996). The role of a computer manipulative in fostering specific psychological/mathematical processes. In E. Jakubowski, D. Watkins, & H. Biske (Eds.), *Proceedings of the eighteenth annual meeting of the North America Chapter of the International Group for the Psychology of Mathematics Education* (Vol. 2, pp. 567-572). Columbus, OH: ERIC Clearinghouse for Science, Mathematics, and Environmental Education.
Scardamalia, M., & Bereiter, C. (1992). An architecture for collaborative knowledge building. In E. De Corte, M. C. Linn, H. Mandl, & L. Verschaffel (Eds.), *Computer-based learning environments and problem solving* (pp. 41-66). Berlin-Heidelberg-New York: Springer-Verlag.
Schery, T.K., & O'Connor, L.C. (1997). Language intervention: Computer training for young children with special needs. *British Journal of Educational Technology, 28*, 271-279.
Schofield, J.W. (1995). *Computers and classroom culture*. Cambridge, MA: Cambridge University Press.
Schrader, C.T. (Cartographer). (1990). *The word processor as a tool for developing young writers*. (ERIC Document Reproduction Service No. ED 321 276)
Shade, D.D. (1994). Computers and young children: Software types, social contexts, gender, age, and emotional responses. *Journal of Computing in Childhood Education, 5*(2), 177-209.
Shade, D.D., Nida, R.E., Lipinski, J.M., & Watson, J.A. (1986). Microcomputers and preschoolers: Working together in a classroom setting. *Computers in the Schools, 3*, 53-61.
Shapira, D. (1995). *Learning to read with joy by using computer-based graphics*. Paper presented at the The Twelfth International Conference on Technology and Education, Orlando, FL.
Shaw, E.L., Jr., Nauman, A.K., & Burson, D. (1994). Comparisons of spontaneous and word processed compositions in elementary classrooms: A three-year study. *Journal of Computing in Childhood Education, 5*(3/4),

319-327.
Sheingold, K. (1986). The microcomputer as a symbolic medium. In P.F. Campbell & G. G. Fein (Eds.), *Young children and microcomputers* (pp. 25-34). Reston, VA: Reston Publishing.
Shields, M.K., & Behrmann, R.E. (2000). Children and computer technology: Analysis and recommendations. *The Future of Children, 10*(2), 4-30.
Shilling, W.A. (1997). Young children using computer to make discoveries about written language. *Early Childhood Education Journal, 24*, 253-259.
Shute, R., & Miksad, J. (1997). Computer assisted instruction and cognitive development in preschoolers. *Child Study Journal, 27*, 237-253.
Silfen, R., & Howes, A.C. (1984). A summer reading program with CAI: An evaluation. *Computers, Reading and Language Arts, 1*(4), 20-22.
Silverman, N.S. (1990). *Logo and underachievers.* Unpublished Masters thesis, University of the Virgin Islands.
Smithy-Willis, D., Riley, M., & Smith, D. (1982, November/December). Visual discrimination and preschoolers. *Educational Computer Magazine,* 19-20.
Snow, C.E., Burns, M.S., & Griffin, P. (Eds.). (1998). *Preventing reading difficulties in young children.* Washington, DC: National Academy Press.
Spiegel-McGill, P., Zippiroli, S., & Mistrett, S. (1989). Microcomputers as social facilitotors in integrated preschools. *Journal of Early Intervention, 13*(3), 249-260.
St. Paul Public Schools. (1985). *Logo Studies*. St. Paul, MN: Author.
Steffe, L. P. (1994). Children's multiplying schemes. In G. Harel & J. Confrey (Eds.), *The development of multiplicative reasoning in the learning of mathematics* (pp. 3-39). Albany, NY: SUNY Press.
Steffe, L. P., & Wiegel, H. G. (1994). Cognitive play and mathematical learning in computer microworlds. *Journal of Research in Childhood Education, 8*(2), 117-131.
Steg, D.R., Lazar, I., & Boyce, C. (1994). A cybernetic approach to early education. *Journal of Educational Computing Research, 10*, 1-27.
Stone, T. T., III. (1996). The academic impact of classroom computer usage upon middle-class primary grade level elmentary school children. *Dissertation Abstracts International, 57-06*, 2450.
Subrahmanyam, K., Kraut, R. E., Greenfield, P. M., & Gross, E. F. (2000). The Impact of home computer use on children's activities and development. *The Future of Children, 10*(2), 123-144.
Swigger, K., & Campbell, J. (1981). Computers and the nursery school. In D. Harris & L. Nelson-Heern (Eds.), *Proceedings of the National Educational Computing Conference* (pp. 264-268). Iowa City, IA: National Educational Computing Conference.
Swigger, K.M., & Swigger, B.K. (1984). Social patterns and computer use among preschool children. *AEDS Journal, 17*, 35-41.
Talley, S., Lancy, D.F., & Lee, T.R. (1997). Children, storybooks, and computers. *Reading Horizons, 38*(2), 116-128.
Tan, L.E. (1985). Computers in pre-school education. *Early Child Development*

and Care, 19, 319-336.
Taylor, B.M., Anderson, R.C., Au, K.H., & Raphael, T.E. (2000). Discretion in the translation of research to policy: A case from beginning reading. *Educational Researcher, 29*(6), 16-26.
Teague, G.V., Wilson, R.M., & Teague, M.G. (1984). Use of computer assisted instruction to improve spelling proficiency of low achieving first graders. *AEDS Journal, 17*, 30-35.
Terrell, S., & Rendulic, P. (1996). Using computer-managed instructional software to increase motivation and achievement in elementary school children. *Journal of Research on Computing in Education, 28*(3), 403-414.
Try, K.M. (1989). *Cognitive and social change in young children during Logo activities: A study of individual differences.* Unpublished Doctorial dissertation, The University of New England, Armidale, New South Wales, Australia.
Turkle, S. (1984). *The second self: Computers and the human spirit*. New York: Simon and Schuster.
Turkle, S. (1995). *Life on the screen: Identify in the age of the Internet*. New York: Simon & Schuster.
Turkle, S. (1997). Seeing through computers: Education in a culture of simulation. *The American Prospect, 31*, 76-82.
Vaidya, S., & McKeeby, J. (1984, September). Computer turtle graphics: Do they affect children's thought processes? *Educational Technology, 24*, 46-47.
Villarruel, F. (1990). Talking and playing: An examination of the effects of computers on the social interactions of handicapped and nonhandicapped preschoolers, *Dissertation Abstracts International, 51-11*, 3630.
Walker, S.L., Elliott, A., & Lacey, d. P.R. (1994). Enhancing language development for young children at risk: The role of computer-based and direct-instruction teacher. *Australian Journal of Early Childhood, 19*.
Warash, B.G. (1984). *Computer language experience approach*. Columbus, OH: National Council of Teachers of English Spring Conference.
Wartella, E., & Jennings, N. (2000). Children and computers: New technology—old concerns. *The Future of Children, 10*(2), 31-43.
Wartella, E., O'Keefe, B., & Scantlin, R. (2000). *Growing up with interactive media*: Markle Foundation.
Wartella, E., Scantlin, R., Kotler, J., Huston, A.C., & Donnerstein, E. (2000). Effects of sexual content in the media on children and adolescents. In C. v. Feilitzen & U. Carlsson (Eds.), *Children in the new media landscape* (pp. 141-153). Göteborg, Germany: UNESCO International Clearinghouse on Children and Violence on the Screen.
Wartella, E.A., & Reeves, B. (1983, June). Recurring issues in research on children and media. *Educational Technology*, 5-9.
Watson, D.M., Cox, M.J., & Johnson, D.C. (1993). *The ImpacT Report: An evaluation of the impact of information technology on children's achievements in primary and secondary schools*. London, UK: King's College, London.
Watson, J. A., & Brinkley, V. M. (1990/91). Space and premathematic strategies young children adopt in initial Logo problem solving. *Journal of Com-*

puting in Childhood Education, 2, 17-29.
Watson, J. A., Lange, G., & Brinkley, V. M. (1992). Logo mastery and spatial problem-solving by young children: Effects of Logo language training, route-strategy training, and learning styles on immediate learning and transfer. *Journal of Educational Computing Research, 8*, 521-540.
Watson, J. A., Nida, R. E., & Shade, D. D. (1986). Educational issues concerning young children and microcomputers: Lego with Logo? *Early Child Development and Care, 23*, 299-316.
Weir, S. (1992). LEGO-Logo: A vehicle for learning. In C. Hoyles & R. Noss (Eds.), *Learning mathematics and Logo* (pp. 165-190). Cambridge, MA: MIT Press.
Wenglinsky, H. (1998). *Does it compute? The relationship between educational technology and student achievement in mathematics.* Educational Testing Service. [Online]. Available: http://www.ets.org/research/pic/technolog.html
White, B. T. (1981). *Designing computer games to facilitate learning.* Unpublished doctoral dissertation, Massachusetts Institute of Technology.
Wiburg, K. M. (1987). *The effect of different computer-based learning environments on fourth grade students' cognitive abilities.* Unpublished doctoral dissertation, United States International University.
Wild, M., & Ing, J. (1994). An investigation into the use of a concept keyboard as a computer-related device to improve the structure of young children's writing. *Journal of Computing in Childhood Education, 5*(3/4), 299-309.
Wright, J. L. (1994). Listen to the children: Observing young children's discoveries with the microcomputer. In J. L. Wright & D. D. Shade (Eds.), *Young children: Active learners in a technological age* (pp. 3-17). Washington, DC: National Association for the Education of Young Children.
Wright, J. L., & Samaras, A. S. (1986). Play worlds and microworlds. In P. F. Campbell & G. G. Fein (Eds.), *Young children and microcomputers* (pp. 73-86). Reston, VA: Reston Publishing.
Yelland, N. J. (1998). Making sense of gender issues in mathematics and technology. In N. J. Yelland (Ed.), *Gender in early childhood* (pp. 249-273). London: Routledge.
Yost, N. J. M. (1998). Computers, kids, and crayons: a comparative study of one kindergarten's emergent literacy behaviors, *Dissertation Abstracts International, 59-08*, 2847.

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Footnotes

1. The Web site for the project lists links to coverage in *U.S. News and World Report* (cover story), *Newsweek*, and *The San Francisco Chronicle*.

2. Papert saw the term "technocentric" as capturing an analogy with the egocentric stage in Piaget's model. As the egocentric child has difficulty understanding anything independently of the self, technocentrism refers to the tendency to give a similar centrality to the computer. This tendency shows up in questions like "what is the effect of the computer on cognitive development?"

3. We attempt a balanced, if not comprehensive, review here. In so doing, we reflect extant research (e.g., numerous studies on Logo and word processing) rather than proportionately reflecting recent popular uses.

4. This is true for all media; "as prior media research has shown, it is not the medium itself that affects children's perceptions, attitudes, or awareness. It all depends on the specific kinds of *content* with which they carry out specific kinds of *activities*, under specific kinds of external or internal *conditions* for specific kinds of *goals*" (Wartella, O'Keefe, & Scantlin, 2000, p. 5, emphasis in original).

5. The distinction is assumed even before research is reviewed in most publications; for example, "Not surprisingly, the effects of computer use vary significantly by the type of activity and the quality of content. The experiences of children playing violent computer games are quite different from those playing educational games; the experiences of children visiting informative, nonprofit Web sites are quite different from those logging on to sites sponsored by media conglomerates and toy companies; and the experiences of children exchanging e-mails with friends and family are quite different from those communicating with strangers in MUDs and chat rooms. What can be gleaned from the

research about the effects of various experiences is summarized below…" (Shields & Behrmann, 2000, p. 9).

6. Further, one might argue that not engaging children in positive uses leaves them more susceptible to developmentally and socially inappropriate uses.

7. Much later, Elkind (1998) moderated his position, stating that he was not opposed to technology but only to it's misuse.

8. *Fool's gold* warns that "the time spent with computers and other electronic media may distract both children and adults from directly communicating with one another, face to face, weaving together the rich variety of spoken and unspoken cues such interactions encourage" (p. 35). There is a concern; unmonitored and unbridled use of the Internet, for example, may lead to less direct face-to-face contact, with potentially negative social consequences (Kraut et al., 1998). However, research, such as that reviewed here, shows that computers used appropriately can support both face-to-face and distance communication to good effect. Further, even video game use outside of school does not lead to social isolation; boys age 11-17 who report frequent game playing were also those likely to see their friends more often out of school; for example, to compare notes (Wartella, O'Keefe et al., 2000). In any case, unqualified, the *Fool's gold* argument is disingenuous: Would the authors wish to stop children from writing letters on paper?

9. Perceptual is used here, consistent with Piaget's original formulation, as meaning phenomena or experiences that depend on sensory input, in contrast to those that are represented mentally (and thus can be "re-presented" imagistically without sensory support). Thus, perceptual should not be confused with the notion that we, with Piaget, reject—that of "immaculate perception" in which perceived objects are immediately registered in the brain.

10. Mathematization emphasizes representing and elaborating mathematically—creating models of an everyday activity with mathematical objects, such as numbers and shapes; mathematical actions, such as counting or transforming shapes; and their structural relationships. Mathematizing involves reinventing, redescribing, reorganizing, quantifying, structuring, abstracting, and generalizing that which is first

understood on an intuitive and informal level in the context of everyday activity.

11. Even home use, not our focus here, has been found to have immediate positive effects on specific cognitive skills and mildly positive effects on academic performance (Orleans & Laney, 2000; Subrahmanyam et al., 2000; Wartella, O'Keefe et al., 2000), although there is not enough research to make clear and general conclusions. Research on one after-school computer program demonstrated far transfer—children who participated in the program achieved significant gains in reading, grammar, mathematics, and computer knowledge; were better able to follow directions; and scored higher on school achievement tests, compared with nonparticipants. The program emphasized voluntary participation in fun and learning activities rather than a structured instructional intervention. Even playing computer games, in moderation, does not negatively impact social skills; the only significant effects have been moderate, positive, influences on forming new friends and bringing family members together (Subrahmanyam et al., 2000).

12. The authors quote a depressing picture: "The eyes stare at an unvarying focal length, drifting back and forth across the screen. Fingers move rapidly across the keyboard or are poised, waiting to strike. The head sits atop the spine balanced, in the words of one physician, like a bowling ball. Built for motion, the human body does not respond well to sitting nearly immobile for hours at a time." The problem is, with only a slight bit of rephrasing, this describes our ten-year-old reading. She never sits at the computer for hours, but she reads for hours. We do move her outside (protected!); we don't call for a moratorium on books. The authors also advise injury if children carry laptops to and from school, but our daughter's books are easily quadruple the weight of a laptop, much less a handheld device. If the authors were anti-textbooks, would they have devoted paragraphs to paper cuts? Nevertheless, myopia may be linked to near reading, and long sessions at the computer may be especially demanding (Palmer, 1993). We should ensure children are not reading anything without adequate breaks (e.g., five minute breaks every 30 minutes, with gazing into the distance every 15 minutes) and lighting (for computers, avoiding overhead fluorescent light reflected on the screen or glare from outside windows).

13. For example, electromagnetic radiation, is an possible but uncertain concern, that seems to be a concern only if quite old equipment is used

and the simplest safeguards ignored. When the authors repeatedly suggest that children go outside, they fail to mention that skin cancer is a proven concern and that safeguards are needed here as well. (And they would undoubtedly not advise against sending children outside because there are dangers there.)

14. Note that parental education appears important, especially for older students: Surveys indicate that about half of all children with home access to the Internet have no parental restrictions on the type of content viewed or the amount of time the Internet is used (Shields & Behrmann, 2000). Given the content available, discussion with parents seems paramount. The issue of time is our next topic.

15. Two caveats should be mentioned: First, this is a correlational study. Second, there is substantial research that CAI drill can have a positive effect, used in certain ways. Our own lack of enthusiasm for this approach does not keep us from reporting the positive research in this domain.

16. Ironically, the authors criticize another report (*President's Committee of Advisors on Science and Technology—Panel on Educational Technology*, 1997) for representing "a narrow range of perspectives" (p. 80).

17. Discussing a similar report, Papert (1998) stated a similar position: "the language of the debate constitutes intellectual pollution, not only because it leaves people muddled and confused about facts but especially because it encourages poor language usage and poor formulation of questions."

18. We credit Mitch Resnick with the specifics of this formulation.

19. The title "*Fool's gold* " may be an attempt to be provocative; instead, it is inflammatory and insulting—Darius' teacher and Anderson are, by logical implication, the "fools" who believe they have found a bit of education gold. Moreover, the way to differentiate gold from pyrite was to carefully assess the material. But the report gives scant indication that the careful tests of educational computer use had been consulted, much less evaluated.

20. What this might mean is beyond the scope of this article, but is discussed at length in many other publications, including our own (Clements, 2000a; Clements & Battista, in press; Clements & Nastasi, 1992; Clements & Sarama, 1997, in press; Clements & Swaminathan, 1995; Sarama, 2000; Sarama, Clements, & Henry, 1998). Among the many suggestions not discussed at length in the present article are included: (a) using high-quality, research-based computer applications that make unique contributions to children's learning and development (example of these are included in software briefly discussed herein); (b) using extensible programs for over extended periods of children's education, so these applications can become tools for thinking; (c) using technology only with adequate professional development (actually beginning with professional development, then deciding on curriculum modifications, software, and hardware in that order); and (d) encouraging thoughtful, slow, adoption and incremental improvement (with reasonable expectations of what technology can do and an appreciation of the importance of the complete educational environment).