Technology and Child Development, Part II:

Lessons from Empirical Research

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ABSTRACT

This report examines primary empirical research from 1990 to the present that evaluates uses of emerging technologies for child development. This paper attempts to answer the questions:

1. What impact does technology used in educational settings have on child development?
2. Which uses of technology hold the greatest promise for improving child well-being outcomes?
3. What future research is needed to understand the impact of technology on children according to cognitive, social, emotional, and physical perspectives?

The paper focuses in detail on 19 controlled, primary research studies on using computer or other advanced technologies in a variety of settings to improve positive developmental outcomes for children. The 19 reports summarized provide valuable insights about our current understandings of the effectiveness of computers in a variety of settings where child development is impacted.

These studies constitute a representative sample of recent research on computer applications to child development, and they aid us in telling a story about what we learned from systematically studying a larger collection of research reports. Computers, wherever they are used, can serve two purposes: as delivery mechanisms, and as tools in and of themselves to promote child development. Computers and other technologies actively involve children in the learning activities to which they are exposed, and facilitate the mastery of simple and complex skills, knowledge, and aptitudes for children. Computers and other technologies greatly increase motivation to learn (and teach), and increase the benefits of collaborative work, play, and other learning opportunities. Computers also allow parents, teachers, care providers, and other adults to facilitate the learning and development of important aspects of child well-being.

INTRODUCTION

This paper, the second of two companion papers, focuses on primary research about the impact technology has on child development and well-being. Here, we concentrate on primary research since 1990[1] that looks at any and all impacts technology has on

[1] Two studies published in 1989 were included in this report because they were considered seminal works for the question at hand, and their late publication dates (in the fourth quarter of 1989) were judged to meet the spirit of the 1990 criteria.

development, learning, cognition, and other aspects of child development. It organizes and interprets research findings, giving special attention to findings based on carefully designed empirical studies. These studies all explore important aspects of child development, especially in (but not limited to) educational settings.

Our initial search of the literature identified 41 comparative primary research studies on the positive effects of computer or other technology use in improving measures of child development. These were all within the content domain covered by this report. A second screen focused on methodological rigor. Of the original 41, this report provides detailed reviews of the 19 studies that met methodological inclusion criteria (comparison groups or opportunity to calculate effect sizes). These studies amplify and extend the general findings reported in our companion paper, and they are each abstracted within. However, our conclusions draw upon all 41 articles identified during the search because of their content-specificity. This report complements research conducted by numerous scientists (Kulik and Kulik 1991; Papert 1993; Honey and Henriquez 1996; Epstein 1992) who have examined the benefits and limitations of advanced educational and communications technologies in enhancing the development of fundamental skills and abilities for children.

STUDY DESIGN, METHODS, AND MATERIALS

Search Strategies and Inclusion Criteria

We modeled our literature review methodology on the methodology used by Emerson and Mosteller (1998a; 1998b) on two studies of interactive multimedia in college teaching. We searched systematically for articles about child health, development, and well-being that included the positive impact of technology, computers, and the Internet. The companion paper (Part I) gives further details of the search strategy used in this project.

This report focuses on primary research articles since 1990 that met each of the following criteria for inclusion:

- Assesses the positive impact of technology on child development and well-being.
- Uses subjects from conception through age 18.
- Uses impact on child well-being as a primary basis for evaluation.
- Provides data that enable the comparison of two or more treatment groups.
- Evaluates impact in the context of environments where children work and live.
- Reports work done in the United States and Canada.
- Uses the term well-being in terms of the asset-based or positive approach (negative outcomes of technology use, such as carpal tunnel among computer users, were considered to be outside the search criteria).

This investigation examined research carried out in a wide variety of academic disciplines, because we wanted to identify patterns that cross disciplinary boundaries. The disciplines included education, psychology, health, and sociology. We sought to distinguish qualitative, case study, and quasi-experimental research about programs and applications from experimental research. We also distinguished research that compared two or more interventions (often with one of the treatment groups being a non-computer control group) from studies that simply described an experience with new uses for computers or new computing environments.

SUMMARY OF SEARCHES FOR RECENT EMPIRICAL STUDIES

We searched systematically for research articles and review articles about technology and child development. Our searches provided more that 350 potentially relevant research articles, reports, and books that have appeared since 1990. Additionally, two seminal works prior to 1990 were included. Altogether, we read and abstracted information from 119 articles, reports, and chapters for this paper. Of those, more than 100 have been published since 1990. A total of 41 studies met the criteria for primary research.

LESSONS FROM NINETEEN EMPIRICAL STUDIES OF THE IMPACT OF TECHNOLOGY ON CHILD DEVELOPMENT

This section reviews and analyzes 19 primary studies of uses of advanced technology in improving developmental outcomes for children. Most of these studies (although not all of them) also reported raw data from which effect sizes could be calculated (see Part I for a description of effect size calculation). In those cases where insufficient data were available from which to compute effect sizes, an attempt was made to contact the original authors. When contact was not possible, the articles were included in this overview but effect sizes were not provided.

Our search revealed articles related to the positive impacts of technology use in school systems, the impact of programming skills on child development, studies related to technology and gender, research on technology and motivation, and studies of special needs students. Therefore, Table 1 organizes and summarizes the 19 primary studies in the following order: (1) general benefits of technology in classroom settings; (2) benefits associated with programming skills; (3) benefits associated with games; (4) technology as motivator; (5) technology and collaborative learning; and (6) technology applied to special needs situations.

We believe that these selected studies, when taken together, can provide a useful perspective on the larger body of primary research on how computers and other technologies can impact child development. We primarily examined those studies that used randomized assignments of treatment and control conditions, both experimental and quasi-experimental. We also examined several studies that, while scientifically less rigorous, tried to achieve comparability among the subjects through statistical adjustment

based on previous measurements of subject outcomes. A detailed synopsis of each study, with appropriate effect size calculations when available, follows the summary table (Table 1).

Table 1: Matrix of Primary Studies of the Impact of Technology on Child Development		
Study Title	**Area and Features**	**Findings**
Category 1: General Benefits of Technology in Classroom Settings		
The Role Of Online Communications In Schools: A National Study, Follansbee, et al. (1996)	Fourth and sixth grade students in 28 elementary schools were randomly assigned to treatment (Internet use in school) and control conditions.	Students with access to the treatment performed better than students in the control groups, scoring higher in all nine learning measures (with statistically significant higher scores in five of the nine measures). Students with online access were more confident in carrying out and presenting research projects.
West Virginia Story: Achievement Gains From A Statewide Comprehensive Instructional Technology Program, Mann, Shakeshaft, Becker, and Kottkamp (1998)	950 fifth graders in 18 elementary schools were selected to represent the range of variables influencing technology use and student achievement. 290 teachers were also surveyed.	Student achievement scores correlated significantly with student experience with model components, accounting for 11 percent of the total variance in the basic skills among fifth graders (although the authors believe this finding under represents the value added by instructional technology).
The Union City Story: Education Reform And Technology—Students' Performance On Standardized Tests, Chang, et al. (1998)	Examines student achievement based on standardized test scores, looking at changes in students' scores prior and subsequent to treatment.	Treatment cohorts had a higher percentage of students passing in every subject every year throughout the study. By the ninth grade, statistically significant associations in reading, writing, and mathematics emerge in the data.
Does It Compute?: The Relationship Between Educational Technology And Student Achievement In Mathematics, Wenglinsky (1998)	Presents findings from a national study of the relationship between different uses of educational technology and various educational outcomes.	The size of the relationships between the various positive uses of technology and academic achievement is negligible for fourth graders but substantial for eighth graders (accounting for more than a one-third of a grade increase).
Exploring Learning Opportunities In Coordinated Network-Enhanced Classrooms: A Case Of Kids As Global Scientists, Songer (1996)	Explores the potentials for learning that exist when students use the Internet to conduct questioning and investigation in middle school science classrooms.	The use of real-time resources and firsthand information has the potential to influence the character of student understandings. Small differences in knowledge development between Internet and comparison groups were found, supported by qualitative findings.
Effects Of Constructivist And Computer-Facilitated Strategies On Achievement In Heterogeneous Secondary Biology, Duffy and Barowy (1995)	Looks at how traditional, constructivist, and computer-facilitated treatments compare for promoting conceptual understanding and critical thinking skills.	There were no significant differences between the conditions in the measures of subject matter knowledge or critical thinking. Constructivist and traditional classes both made significant "gains" in content knowledge, while computer-facilitated classes did not change significantly.
Category 2: Benefits Associated with Programming Skills		
Learning Preproof Geometry with LOGO, Lehrer, Randle, and Sancilio (1989)	LOGO programming was compared to traditional inquiry-based instruction for geometric concepts.	Children instructed with LOGO were better able to apply their learnings, improving elaborations of procedural interpretations in geometry.
Some Prerequisites for Teaching Thinking: Methodological Issues in the Study of LOGO Programming, Littlefield, Delclos, Gransford, Clayton, and Franks (1989)	An experimental evaluation of claims that learning LOGO enhances children's general thinking skills was conducted.	Flaws in past studies and consideration of teaching methods are discussed. Performance in prompted testing situations showed significant differences for the experimental group.
Relationships Among Cognitive Components in LOGO Learning and Transfer, Lehrer and Littlefield (1993)	A model of relationships among cognitive components related to the acquisition and transfer of LOGO was developed and tested.	Systematic mediation of LOGO learning was equally effective whether presented with or without the larger framework of a macrocontext. Transfer is regulated by a system of relationships among the cognitive components tested.
Effects Of LOGO Instruction On Cognitive Style, Cathcart (1990)	Pre- and post-cognitive style tests were administered to students exposed to instructional LOGO and a control group.	Children exposed to LOGO scored significantly higher on the posttest in divergent thinking and field dependence/independence. Group effects were evident on two of the divergent thinking subtests but not on the total score.

Category 3: Benefits Associated with Games		
Effects Of Video Game Playing On Measures Of Spatial Performance: Gender Effects In Late Adolescence, Okagaki, and Frensch (1994)	Spatial ability, mental rotation, and visualization skills of adolescents were tested using a popular video game.	Using technology improves mental rotation time and spatial visualization time, both for boys and girls. Boys performed better than girls in only the most complex mental rotation tasks.
Interaction, Gender, And Performance On A Computer-Based Problem Solving Task, Barbieri and Light (1992)	Working in mixed- and same-gender pairs, boys and girls were tested on problem-solving skills, in pairs and alone.	Modest significant correlations were found for verbal explicit planning, negotiation, etc. and examined in terms of success for pairs and individuals. Gender differences were independent of pair type and verbal interactional measures used.
Effect of Video Game Practice on Spatial Skills in Girls and Boys, Subrahmanyam and Greenfield (1994)	The effect of video game practice on spatial abilities in girls and boys was studied.	Spatial performance was significantly better for boys than girls, and video game practice was significantly more effective than the control method in improving spatial performance on the posttest measures. Improvement was best for children who started with poor spatial skills.
Category 4: Technology as Motivator		
Intrinsic Motivation and the Process of Learning: Beneficial Effects of Contexualization, Personalization, and Choice, Cordova and Lepper (1996)	Enhancement of student intrinsic motivations was examined for three strategies—contextual-ization, personalization, and provision of choices.	Improvements in all three strategies were recorded for both motivation and increased depth of engagement in learning, amount learned in a fixed time period, and perceived competence and levels of aspiration.
The Development Of Children's Writing Awareness And Performance Within A Generative / Evaluative Computerized Prompting Framework, Bonk and Reynolds (1990)	Examines the use of generative and evaluative computerized prompting framework to improve the teaching of writing skills among 164 children, grades six through eight, with high and low writing skills.	Differences in holistic performance, metacognitive guidance in writing, surface revisions, and repositioning within papers between grades six and seven were not found between grades seven and eight, suggesting that a developmental change had occurred between grades six and seven. The findings further suggest that procedural assistance may be most appropriate in grade six.
Category 5: Technology and Collaborative Learning		
The Relationship Between Type Of Knowledge And Process Of Peer Collaboration In A Computer-Mediated Classroom, Oshima (1993)	Examines how students acquire their knowledge through peer collaboration in computer supported intentional learning environments.	Higher achievers planned their learning in advance and made strategic use of databases compared to less-successful students, and spent more time in metacognition efforts than did their peers. They also more adeptly incorporated personal resources in the classroom to construct theories.
Video Training As A Means Of Enhancing Self-Awareness In Problem Solving Among Young Children, Fireman and Kose (1991)	Conditions that facilitate children's self-regulation of problem solving activities were examined in two pre- and posttest designs. Tower of Hanoi problems were used to assess effects of training and practice on performance.	Training with a model hindered descriptions of solutions and performance of the generalization task, while the video training condition facilitated the regulation of problem solving activities. Using video to allow students to view their own previous performance of the problem solving task was superior to other training methods.
Category 6: Technology Applied to Special-Needs Situations		
Increasing Reading And Communication Skills In Children With Autism Through An Interactive Multimedia Computer Program, Heimann, Nelson, Tjus, and Gillberg (1995)	The effects of using an interactive and child-initiated microcomputer program when teaching groups of children reading and communications skills were examined.	Significant gains were realized for some groups during the intervention period for reading and phonological awareness. The intervention succeeded in stimulating verbal expressions among some groups.
Computer Intervention for Adolescent Children of Divorce, Barker, Brinkman, and Deardorff (1995)	This study explored the learning and effects of teens and parents participating together in an educational computer-based divorce adjustment program.	Utilizing the program did not improve knowledge needed for divorce adjustment, although parents and teens reported an increase in understanding and communication and a decrease in conflicts as a result of the intervention.

SUMMARIES

***The Role Of Online Communications In Schools: A National Study*. (1996).** Follansbee, S., Gilsdoft, N., Stahl, S., Dunfey, J., Cohen, S., Pisha, B., and Hughes, B.

In this study, Follansbee and colleagues demonstrated that students with online access performed better than those without online access in completing research assignments. The study isolated the impact of online use and measured its effect on student learning in the classroom. The study compared the work of 500 students in 28 fourth grade and sixth grade classes in seven urban school districts (Chicago, Detroit, Dayton, Memphis, Miami, Oakland, and Washington DC). Half of these classes (14) served as experimental groups with online access; the other half were the control classes without online access. In each city, two classes in each of two schools were selected: an experimental and control fourth grade class from one school, and an experimental and control sixth grade class from the other school.

Both experimental and control groups carried out a common unit of study based on the school's curriculum in conjunction with a curricular framework, activities, and worksheets developed by the researchers for the study. Both control and experimental classes were advised to use computers whenever appropriate. Only the experimental classes, however, were allowed to take part in online resources, activities, and communication. In both groups, the emphasis was on integrated learning and helping students to see connections among people, their actions, and the real world. Two main research questions were investigated: (1) the impact of online use on student performance and attitudes; and (2) the impact of online use on teacher behavior and attitudes. Student performance and attitudes were clarified by looking at the effects of online use on: (1) student projects; (2) student perceptions as reported on questionnaires; and (3) teacher reports of student performance. Teacher behavior and attitudes were clarified by looking at the effects of online use on: (1) teacher perceptions as reported on questionnaires; and (2) teacher reflections as reported in phone interviews.

The results show significantly higher scores on measurements of information management, communication, and presentation of ideas for experimental groups with online access than for control groups with no online access. The study offers evidence that using the Internet can help students become independent critical thinkers, able to find information, organize and evaluate it, and then effectively express their new knowledge and ideas in compelling ways.

***West Virginia Story: Achievement Gains From A Statewide Comprehensive Instructional Technology Program*. (1998).** Mann, D., Shakeshaft, C., Becker, J., and Kottkamp, R.

In 1989-1990 a basic skills/computer education (BS/CE) program was authorized for schools in West Virginia. Beginning with the kindergarten class of 1990-91, hardware

and software were installed in schools and teacher training began. The program consisted of three basic components: (1) software that focused on the State's basic skills goals in reading, language arts, and mathematics; (2) enough computers in the schools so that all students were able to have easy and regular access to the basic skills software; and (3) professional development for teachers in the use of the software and the use of computers in general. Beginning with the 1990-1991 kindergarten class, the State of West Virginia annually provided every elementary school with enough equipment so that each classroom serving the grade cohort of children targeted that year might have three or four computers, a printer, and a school-wide, networked file server. Schools could choose to deploy the computers in labs and centers or distribute them directly to classrooms. As the 1990-91 kindergarten class progressed through the grades, so did the successive waves of new computer installations, coupled with intensive professional development for teachers. Data were collected from 950 fifth graders in 18 elementary schools. These schools were selected to represent the range of variables that might influence technology use and student achievement.

The study showed statistical significance at the .001 level on several measures. The 1996-97 fifth graders had the most complete test score records, and they were the first cohort to have had the consistent availability of BS/CE across their entire school experience. Data from 290 teachers were also collected for the study. The BS/CE technology regression model accounted for 11 percent of the total variance in the basic skills achievement score gains of the fifth grade students. "Not only is there a statistically significant relationship between BS/CE and test score gains; and not only can these gains be translated into effect sizes comparable to those of other interventions, but also the gains from programs that update BS/CE's positive features can be achieved at a much lower cost than could similar gains from a currently very popular alternative intervention, namely, class size reduction" (Mann et al. 1998, 50).

The researchers believed, however, that the 11 percent variance underestimated the value added by instructional technology. This analysis established how much value could be added on a statewide basis from a sustained instructional technology initiative. The data indicated that as much as a third of the gains in "school accessible achievement" can be powered by instructional technology. Mann and his colleagues calculated an overall effect size for their study, not an effect of control versus condition, but an effect of more of the factors being examined versus fewer of the factors. This overall effect size constituted the sum of effect sizes of all of the components of the study. The point is not which individual components of the model were most effective but rather that all the components of the model taken together made a difference. Assuming that there is no co-linearity among the nine factors examined in the study, there is some logic in simply summing the size of each of the effects. That yields a total effect of all significant factors of ES = 1.074.

***The Union City Story: Education Reform And Technology—Student's Performance On Standardized Tests*. (1998).** Chang, H., Henríquez, A., Honey, M., Light, D., Moeller, B., and Ross, N.

In this report, Chang and his colleagues investigated the impact of state-of-the-art networking technologies in a reformed educational context on students' learning, teachers' teaching, and parental involvement. The findings were based on standardized test results for student achievement. To examine the impact that the reforms had on students' test performance, researchers looked first at the changes in students' scores prior and subsequent to the district's reform initiatives. They based these analyses on tests administered by the district at the first, fourth, eighth, ninth, and tenth grade levels. A more in-depth analysis was based on a cohort of students who had sustained access to networked technology at home and at school, and a cohort of students who had more limited school-only access to technology. The analyses presented in the article are based on testing data at the seventh through tenth grade levels.

Results indicated that the educational reforms undertaken by the Union City district had a substantial impact on students' standardized test performance, particularly at the K-8 level where the reforms were in place the longest. Also, the cohort of students with access both at home and at school gained a substantial "leg up" during the first year of the project, scoring significantly better than their district peers in writing and mathematics (although the increase cannot be attributed to the technology alone). Writing is the one area where deep and sustained access to technology made a difference.

Table 1 reports the effect sizes for writing, math, and reading outcomes for junior high cohorts. At the seventh, eighth, and ninth grade levels, the dual-access cohort did significantly better than the other cohort on the writing portion of state tests at each grade level. Student performances in math scores also showed significant gains, although the impact on reading was not significant.

Table 2: Effect sizes of intervention on measured outcomes in three subjects by cohort

Subject Area	7th	8th	9th	10th
Writing	.617	.203	.498	.062
Math	.679	.183	.498	.732
Reading	-.16	.019	.164	.025

Experimental condition students, followed from seventh through ninth grades, also performed better in math and writing than in reading (see Table 2). The researchers concluded that technology is not the sole cause of the dual-access cohort's success and that a range of factors, both contextual and technology-facilitated, made a difference in the cohort's superior performance.

Table 2: Effect sizes of intervention on measured outcomes for longitudinal cohorts

Subject Area	Cohort	Effect Size
Writing	7th through 8th	.399
	7th through 9th	.549
Math	7th through 8th	.373
	7th through 9th	.389
Reading	7th through 8th	.213

***Does It Compute?: The Relationship Between Educational Technology And Student Achievement In Mathematics*. (1998).** Wenglinsky, H.

In this study, Wenglinsky determined that technology could have positive benefits when used in mathematics instruction. However, the author cautioned that those benefits depend on *how* the technology was used. He indicated that prior to the study, most research on technology's effectiveness consisted of small case studies, some of which examined just one or two classrooms at a time. This study breaks new ground by analyzing a national database of student test scores, classroom computer use, and other information, including school climate. The study used data on fourth and eighth graders who took the math section of the 1996 National Assessment of Educational Progress (NAEP); an assessment used by the U.S. Department of Education for over 25 years to monitor student achievement. Beginning in 1996, the NAEP assessment included questions about how computers were used in mathematics classrooms, thus allowing for studies of relationships between computer use and achievement.

After adjusting for class size, teacher qualifications, and socioeconomics, the author found that technology had more of an impact in middle schools than it did in elementary schools. Students in eighth grade, where computers were used for simulations and applications, had higher test scores than those students who used computers for drill-and-practice. The differences were equivalent to half a grade level's achievement. Fourth grade students who used computers primarily for "math/learning games" scored higher than students who did not. Unlike the eighth graders' scores, fourth graders showed no differences in test score gains for either simulations and applications or drill-and-practice. In addition, students of teachers who had appropriate professional development in computers scored one-third of a grade level higher than students whose teachers did not have such training.

***Exploring Learning Opportunities In Coordinated Network-Enhanced Classrooms: A Case Of Kids As Global Scientists*. (1996).** Songer, N.

Songer described the Kids as Global Scientists (KGS) project as one which examined the potential for learning that exists when students use the Internet to conduct questioning and investigation in middle school science classrooms. Topics discussed included the

design of a learning environment that takes advantage of particular features of Internet-based classroom learning, the necessary conditions for facilitating learning, the challenges encountered in facilitating the learning, and overall changes in schooling. The major goal of Songer's research was the exploration of learning potential—the study of students' knowledge development as it progresses from less articulate and less integrated understandings to increasingly complex and explanatory forms.

The specific goals of the KGS project were to develop, enact, and study the impact of a six-week weather curriculum utilizing telecommunications resources. Students answered 20 open-ended questions before and after the study to assess understanding of weather knowledge. One of the major hypotheses was that the combination of specific learning approaches and the use of networks in middle school classrooms would influence the type of knowledge developed by students. Songer tested the distributed-expertise learning approach and capitalized on email and the Internet's ability to provide information quickly. Project participants included 230 middle school students in six locations (seven classrooms). The Internet classrooms performed research and exchanged information using telecommunications networks. Comparison classrooms followed the same learning approach and curricular sequence, but used only traditional offline resources. The Internet classrooms exchanged information with students in all of the other locations, but the comparison students only interacted with students in their own school. For the first three weeks, students worked in groups of two or three to become experts in one particular area of local weather. The students received focused curriculum questions related to their topic area, then collected information using hands-on data collection, experiments, questioning of local experts, and other means.

During the last three weeks of the study, students were instructed to gain more information on local science by sending questions to peers studying the same topic in different places. At the end of the study, 16 students (eight from each group) gave detailed interviews to clarify understanding of responses on the pre- and post-unit tests. Also, final group portfolios were collected which represented group work on all the unit activities. The researchers also studied email dialogues and videotapes of classroom activities. The study suggests that the use of real-time resources and firsthand information has the potential to influence the character of student understandings. Although the factual, written assessments displayed only small differences in knowledge development between the Internet and comparison students, the observed qualitative differences between the groups were important according to the author. Some examples include: role changes for project participants including the addition of new participants in task work and shifting roles for continued participants; the potential for more personal, intermediate-level explanations of science phenomena; and new opportunities for increased motivation to learn.

***Effects Of Constructivist And Computer-Facilitated Strategies On Achievement In Heterogeneous Secondary Biology*. (1995).** Duffy, M., and Barowy W.

In this article, Duffy and Barowy addressed two research questions: how do three treatments—traditional, constructivist, and computer-facilitated—compare in promoting (1) conceptual understanding, and (2) critical thinking skills. Fifty-six students comprising "secondary biology classes" served as subjects for the study. Three classes were used, all taught by the same teacher. One class received a traditional curriculum (didactic, fact-oriented, etc.), while the other received a constructivist curriculum (students directed the activities and worked in groups). The third group received a "computer-facilitated" curriculum, where the students used an interactive simulation model to replace the teacher lectures. The model required students to learn the intervention material on their own. Students in this group interacted with the software twice over the course of the study.

There were no significant differences between the conditions in the measures of subject matter knowledge or critical thinking. The constructivist and traditional classes both made significant "gains" in content knowledge, but the computer-facilitated class did not change significantly from pre- to posttest. The traditional class may have made significant gains in content knowledge, but it was difficult to say definitively because the content test largely measured factual knowledge. The computer-facilitated condition may have been least successful for three reasons. First, students in the computer-facilitated condition did not have the benefit of interacting with the teacher (the computer simulation only embodies content knowledge, while the teacher has years of experience and the accompanying pedagogical content knowledge). Second, students in the computer-facilitated condition also spent considerable time learning to use the software, rather than focusing on the intervention material. Third, students in the computer-facilitated condition did not have a closing discussion (though research indicates that use of technology in the schools must be accompanied by good curriculum and teaching to be successful).

The authors closed with suggestions for future research for investigating the success of computer-facilitated interventions in teaching, since the main finding of this paper indicated that there was no real difference in students' learning in traditional, constructivist, or computer-facilitated classes. The project also highlighted the difficulty of doing this sort of "horse-race" comparison, since it is difficult (or perhaps impossible) to control factors to truly test the effect of just the technology. One concern with the paper was that there is no mention of how long the students experienced any of the treatments.

***Learning Preproof Geometry with LOGO*. (1989).** Lehrer, R., Randle, L., and Sancilio, L.

Lehrer and his colleagues examined measures of attitudes, knowledge acquisition, knowledge application, and knowledge organization with 32 fourth graders who had all

previously used LOGO[2]—a computer programming language that some believe increases problem-solving skills for those who learn it. Students were assigned by mathematical ability randomly to one of two conditions for instruction in geometry concepts, such as lines, angles, and quadrilaterals. Children in both conditions received inquiry-based instruction and identical declarative specifications of preproof geometric concepts. In one condition, procedural specifications of the geometry concepts employed traditional construction tools, such as protractors and rulers; in the other condition, procedural specification of the concepts entailed the use of a modified form of LOGO. Following the instruction phase of the project, children responded to measures of attitude, knowledge acquisition, knowledge application, and knowledge organization.

Effect sizes of the treatment ranged from -.25 for angle identification to 1.55 for intersection. Lehrer and his colleagues noted that the largest effect sizes were associated with the ordered relations, necessary and sufficient properties, and intersection; all measurements of geometric knowledge. The measures of knowledge organization suggested that there were instructionally related differences in the representation of some of the geometric concepts. Children using traditional tools and methods for geometric concepts were more likely to attend to surface features of the subject matter than were their treatment peers. However, no differences between instructional conditions were observed for either attitude or knowledge acquisition of geometric concepts. Children using LOGO, however, were better able to apply what they had learned, both at immediate and two long-term posttests (10 and 16 weeks), compared to children in the control condition.

The results suggest that LOGO is an effective means for elaborating children's procedural interpretations of some preproof geometry concepts. Using LOGO provides an introduction to paradigmatic reasoning (Bruner 1986), or reasoning that disclaims the importance of particulars in favor of reasoning to the general. LOGO provides practice for the development of well-formed arguments. Lehrer stated that this path is "better than the road not taken" (182).

***Some Prerequisites for Teaching Thinking: Methodological Issues in the Study of LOGO Programming*. (1989).** Littlefield, J., Delclos, V., Gransford, J., Clayton, K., and Franks, J.

Given that much attention has been paid to the cognitive benefits to be gained by children who learn LOGO, this study attempted to experimentally evaluate the claims that learning LOGO actually enhances children's general thinking skills. Attempting to meet the methodological concerns of past LOGO research, a study was designed to determine whether a structured teaching method was more effective than an unstructured, discovery-oriented method in achieving language mastery and transfer of general skills. Littlefield and his colleagues examined three groups of fifth graders (a structured learning

[2] LOGO is a computer programming language designed to help children learn mathematical concepts and problem-solving skills. Created by Seymour Papert in the late 1970s, LOGO has been widely used and tested as a learning tool. For more information about LOGO, see Papert, 1993.

group, an unstructured learning group, and a control group) with subgroups varying in terms of the subjects' previous academic success level (successful or less successful). The structured and unstructured groups were taught LOGO for one hour per day, five days per week, for five weeks, while the control group received the standard educational curriculum.

Results with measures of LOGO mastery showed significant differences favoring the structured group on items requiring anything more than basic knowledge of LOGO commands. That is, students performed better in advanced tasks when they were in more structured environments. Effect sizes for dynamic difference scores ranged from .75 between structured (successful) subjects and control subjects to .15 for unstructured (successful) and control subjects. Pre- and posttest measures of general thinking skills, however, showed no differences between experimental and control students on tests of students' independent performances. The authors did report that for a few conditions measures showed significant differences favoring the experimental group.

The lack of strong significant findings in this study speak to the point that the authors attempt to make, namely, that claims that LOGO enhances cognitive learning and problem solving need to be carefully examined. Advances in technology, especially microcomputers, have led to what the authors call, "speculation," that computers can play an important role in developing people's abilities to think, learn, and solve problems. Papert (1980) suggested, for example, that the experience of programming computers in LOGO is especially conducive to the development of problem-solving skills. Littlefield and colleagues stressed that three important issues must be considered when making such claims: (1) Training conditions used in experiments must be carefully defined; (2) demonstrated reliability of measures that indicate a subject has learned the programming language, and; (3) full descriptions and justification of the measures used to test for training effect transfer (i.e., from the ability to program in LOGO to other life skills). They also emphasized the importance of the teaching method used to train students in LOGO; as in this study, two teaching methods produced differing results.

***Relationships Among Cognitive Components in LOGO Learning and Transfer*. (1993).** Lehrer, R., and Littlefield, J.

Lehrer and Littlefield created a model to represent their initial conjectures about direct and indirect relationships among cognitive components for learning LOGO and transfer to related problems. Their model looked at four major components: resources (i.e., working memory); representations (i.e., the ways in which knowledge of LOGO is organized); metacognition (i.e., monitoring solutions and detecting errors in programs); and performance (e.g., solving problems and designing executable programs in LOGO). These components correspond to Sternberg's (1985) categories for "general" information processing and incorporate information about domain-specific components identified in prior research with LOGO. Such studies consistently indicate the importance of the instructional method and of the goals pursued when one instructs children in the use of LOGO.

Exploring this belief, the authors investigated what effects different implementations of mediated instruction had on LOGO knowledge and transfer. Two implementations of mediated instruction were compared with respect to these four components and to measures of transfer. One approach focused on microcontest-based instruction (limiting mediation to examples and ideas encountered only during LOGO-related activities). The other was macrocontest-based, with instruction considering not only relationships within LOGO, but also relationships between LOGO and non-LOGO problems. Forty-eight second grade students were grouped by achievement, and then randomly assigned to one of two instructional conditions: micro- or macrocontext. Students were selected from two intact second grade classrooms with half the students in each class assigned to each instructional condition.

Few reliable differences were found between instructional conditions, indicating that the systematic mediation of LOGO learning was equally effective whether presented with or without the larger framework of a macrocontext. The authors speculate that this may be a result of both conditions acting as macrocontexts given that the process of design included in both conditions may have accomplished many of the goals of a macrocontest, including the establishment of a theme and the continuity implied by that theme. The study continues the development of adequate measures of the kinds of knowledge developed and transferred from a LOGO learning experience. It also provides guidance as to the kinds of measures that must be developed to adequately answer the question of what one learns when one learns to program and use computer languages. It makes clear that similarity between LOGO and transfer tasks involves a system of relationships that spans declarative and procedural knowledge, as well as cognitive resources, such as working memory.

***Effects Of LOGO Instruction On Cognitive Style*. (1990).** Cathcart, W.

Researchers and educators are unsure about the effect of computer experiences on children's thinking. Educational leaders like Papert (1993) have argued that when children experience the LOGO language they learn much more than the language itself (i.e., problem-solving skills that can be applied to other areas of their lives). Many researchers are skeptical, arguing that there is not much empirical evidence to support such claims. There are numerous studies of LOGO and its use in educational settings, many of which indicate that the LOGO experience has some positive effects on some aspects of cognition and cognitive style. Cathcart reports on three measures of cognitive style: divergent thinking, field dependence and independence, and impulsivity and reflectivity. Twenty-five experimental fifth grade students were given an instructional / experimental program in LOGO for fourteen weeks. A control class of eighteen students had no LOGO experiences during this time but did have occasional access to a computer for CAI purposes. There were no significant pre-test IQ differences between treatment groups for verbal, quantitative, and nonverbal intelligence. Both groups were administered three cognitive style tests prior to and immediately following the instructional period.

The experimental group scored significantly higher on the posttest in divergent thinking and field dependence / independence than did their control-treatment peers. Effect sizes for divergent thinking, field dependence and independence, and impulse and reflectivity could be calculated. A medium effect size of the treatment was established for divergent thinking (ES = 0.458), and for field dependence and independence (ES = 0.400). The effect size for impulsivity and reflectivity (ES = 0.292) was smaller but approached a medium effect. When the classes were compared, group effects were evident on two of the divergent thinking subtests, but not on the total score. On both subtests, differences were due to better posttest performances by the experimental group than the control group. These findings suggest that instruction in LOGO may have some effect on cognitive style, in that over the course of a short-term instructional program, the experimental students became more divergent in their thinking and more field independent, but not significantly more reflective.

***Effects Of Video Game Playing On Measures Of Spatial Performance: Gender Effects In Late Adolescence*. (1994).** Okagaki, L., and Frensch, P.

The meteoric rise of video games over the last decade has led to a corresponding rise in the emotional debate regarding the consequences of video game playing. Do video games, like other games, provide a context that encourages positive development? Okagaki and Frensch presented a study that was guided by the belief that, partly because of their enormously and intrinsically motivating qualities, video games do indeed have great potential as educational tools. This paper reported on two empirical studies conducted with older adolescents who played *Tetris*, a video game requiring the rapid rotation and placement of seven different-shaped blocks. Since none of the subjects had ever played *Tetris* prior to the studies, the researchers contended that playing the game increased performance on spatial and perceptual speed. This contention was examined in the two studies.

In Experiment One, subjects were pre- and posttested with paper-and-pencil measures of spatial ability. Students in the experimental condition played six hours of Tetris, while students in the control condition refrained from playing any video game prior to posttesting. Effect sizes for playing the game can be calculated for four performance measures: (1) perceptual speed (ES = -0.09 for boys and ES = -0.186 for girls, ns); (2) card rotation (ES = 0.128 for boys and ES = 0.378 for girls, $p<.05$); (3) cube comparisons (ES = 0.781 for boys and ES = 0.25 for girls, $p<.05$); and (4) form board (ES = 1.252 for boys and ES = -0.124 for girls, $p<.05$). This indicates that practice was of more benefit to boys than girls for cube comparisons and form board activities. Girls, on the other hand, benefited more from practicing card rotation than did boys.

To test whether game playing improved participants' scores on the spatial performance measures, four separate ANOVAs were conducted with group (experimental vs. control) and gender as between-subject variables. The dependent variables were participants' change scores (Time 2 minus Time 1) on the four spatial performance measures. These

analyses revealed a main effect for gender, F (1, 53) = 5.28, $p < .05$, with boys improving more than girls, and an interaction between gender and group, $F(1, 53) = 5.62$, $p < .05$, on cube comparison tests. Preliminary results indicated a general pattern of score indicating that boys tended to show greater improvements in spatial performance than girls as a result of game playing. Therefore, the researchers performed one-way ANOVAs with group as the between-subject variable (on card rotations, cube comparisons, and form board tests) separately for boys and girls. For boys, the main effect of group was reliable for both the cube comparisons and form boards tests, $F(1, 31) = 14.07$, $p < .001$, and $F(1, 31) = 4.56$, $p < .05$, respectively. In contrast, none of the effects were reliable for girls.

In Experiment Two, computerized measures of mental rotation and visualization skills were administered to a sample of 53 students. Subjects were randomly assigned either to the control or the experimental group. The dependent variables of interest were subjects' reaction times on the mental rotation task and the visualization task, as well as measures representing the quality of game-playing performances for subjects in the experimental condition. The independent variables were group, gender, and time of testing. Effect sizes can be calculated for the rotation task of Tetris shapes (ES = 1.718 for boys and ES = 1.296 for girls; NS), and for non-Tetris shapes (ES = 1.304 for boys and ES = 0.143 for girls; $p<.001$).

In both studies, experimental subjects' pre- and posttest scores were compared to pre- and posttest scores obtained from a control sample of subjects. Results indicated that playing *Tetris* improves mental rotation time and spatial visualization time. Consistent with earlier research, reliable differences between males and females were obtained only on complex mental rotation tasks (i.e., the non-Tetris shapes). This demonstrated that skills acquired through playing a video game could be generalized to different shapes. Another implication of this study is that adolescent video game players can accrue some specific cognitive benefits from the time they spend playing video games.

***Effect of Video Game Practice on Spatial Skills in Girls and Boys*. (1994).** Subrahmanyam, K., and Greenfield, P.

Informal education takes place by means of a host of cultural tools, among which the electronic media have become increasingly important. Whereas the impact of explicitly educational computer formats has been amply studied, recreational forms of computer use have been relatively ignored as a means of informal education. Chief among these is the action video game. Much attention has been paid to the negative effects of video games that glorify violent behaviors, but little attention has been paid to the role or benefits computers and video games play in the development of literacy skills that are distinct from the traditional print literacy skills taught in schools. Subrahmanyam and Greenfield concluded that the effects of video game training and practice fit within a view that cultural tools and artifacts are related to cognitive developmental processes.

Given the growing importance of computers and video games as modern tools, the authors opined that there is both theoretical and pragmatic interest in examining the effect

of video game play on cognitive skills. Spatial representation is one example of an everyday cognitive skill that can be enhanced and developed by video games and other computer applications. The researchers conducted a study of the effect of video game practice on spatial abilities in girls and boys. The sample included 61 subjects, 28 boys and 33 girls in the fifth grade, divided randomly into experimental and control groups. A video game that required the use of spatial skills to guide objects, judge speeds and distances of moving objects, and intercept objects was selected. Preliminary work with the game also indicated that it was fun and challenging for the children, increasing their motivation to do well when playing. A second, text-based game with no spatial components was used for the control condition. Spatial performance, measured using two subtests of a computerized spatial skills battery, was significantly better in boys than in girls during pretest assessment. The study used a 2 X 2 X 2 design where gender and experimental condition were between-subject independent variables, time of testing (pre- and posttest) was a within-subject independent variable, and spatial skill was the dependent variable. To determine the effect of video game practice on error scores, a repeated-measures analysis of variance (ANOVA) was performed, with the composite spatial ability score as a repeated measure, and gender and experimental conditions as the between-subjects variables.

Analysis indicated a significant two-way interaction of experimental condition and time of test ($F(1, 47) = 5.00$, $p = .03$). The two-way interaction indicated that video game practice resulted in improved relative performance on the spatial tests whereas the computerized word game did not. No main effect or interaction effect involving gender was obtained. As predicted, subjects who were initially low in spatial skills benefited significantly from video game practice ($t(11) = 3.65$, $p = .004$). Although experimental subjects improved significantly as a result of video game play, they did not catch up with the groups who started out with high spatial skills on the pretest. The pattern of results suggests that video games may be useful in equalizing individual differences in spatial skill performance, including those associated with gender.

***Interaction, Gender, And Performance On A Computer-Based Problem Solving Task*. (1992).** Barbieri, M.S., and Light, P.H.

A 1990 review of the literature on collaborative learning at the computer indicated that pairs or small groups often show better learning outcomes than individuals, and that even when this is not the case, the results obtained by pairs are never inferior to those obtained by small groups (Light and Blaye 1990). Given that results of different studies are often inconsistent, Beriberi and Light conducted a study examining the interactional and cognitive dynamics underlying productive interactions in learning. The subjects of this study consisted of 66 eleven and twelve year-old children, drawn from two parallel classes of the same school. The sample included 33 boys and 33 girls, and subjects were randomly assigned to form 11 boy-boy pairs, 11 girl-girl pairs, and 11-girl-boy pairs. The task the pairs were assigned to complete consisted of a fantasy-quest problem solving exercise, where the children had to retrieve an object from a virtual island and return it to a specified location. They did this by giving “orders” to characters within the

program, each of which was capable of specific functions that the others could not execute.

Following training with the software, students comprising the pairs were left to solve the problem (while being observed). At a follow-up session two weeks later, students again needed to solve a slightly different problem, this time individually. Children could achieve different levels of success in the solution of the task, depending on how close they came to solving the problem. The level of success in the first session was coded as a "pair" measure, while the level of success in session two was coded as an "individual" measure. Videotapes of the paired interactions were analyzed in terms of planning, negotiations, and teamwork interactions that could be verbally determined. These interaction variables were examined in relation to the levels of success attained, both as a pair and at individual posttest. Additionally, three non-verbal interaction and rating measures were created, all referring to mouse control.

Significant, though fairly modest levels of correlation were obtained between team and individual problem-solving success. Analysis also focused on the issue of gender, with the different gender pairings producing different patterns of interaction. The substantial advantage of boys over girls in terms of final performance turned out to be largely independent, both of pair type and of the verbal interactional measures used. The results indicate that verbal measures derived to index planning, negotiations, and the shared construction of knowledge about the task were significant predictors of the efficacy of the pairs in terms of their success as a pair, and the subsequent success of individuals from that pair when working alone. The capacity to create a shared representation of the task seemed to be important when considering the effects of the interaction on both members of the pair.

In this study, gender differences did not provide a clear association with gender or pair type, although gender and pairing effects were apparent in interactions concerning who controlled the mouse. Control switches occurred most frequently in girl-girl pairs with short and frequent turns. This finding is negatively correlated with successfully completing the task.

***Intrinsic Motivation and the Process of Learning: Beneficial Effects of Contexualization, Personalization, and Choice*. (1996).** Cordova, D., and Lepper, M.

Cordova and Lepper conducted an experiment that examined the effects on the learning process of three complementary strategies (contextualization, personalization, and provision of choices) for enhancing students' intrinsic motivation. The sample included 31 male and 41 female fourth and fifth grade students from two private elementary schools in California. Children were randomly assigned, within-gender, to one control and four experimental conditions. The children worked with educational computer activities designed to teach arithmetical order-of-operations rules. In the control condition, this material was presented abstractly. In the experimental conditions, identical material was presented in meaningful and appealing learning contexts, in either

generic or individually personalized form. Half of the students in each group were also offered choices concerning instructionally incidental aspects of the learning contexts; the remaining students were not.

The effects of personalization and choice on each of the dependent measures were examined using a general one-way analysis of variance (ANOVA) with four orthogonal planned contrasts. Intrinsic motivation effects were examined and yielded highly significant overall treatment effects, revealing that students who engaged in fantasy play, and who were allowed to personalize their gaming experiences, enjoyed the program of study more than their control peers ($F(1, 65) = 33.02$, $p < .0001$; and $F(1, 65) = 21.79$, $p < .0001$ respectively). Other significant effects were found for task involvement measures, indicating that motivation improves task involvement. For example, students in the experimental conditions made use of complex operations in their assignments (e.g., parentheses, negative numbers, division, etc.) more frequently than did their control peers. These patterns of significance held for effects on learning, on perceived competence, and on level of aspiration. Analysis of covariance (ANCOVA) used pretest scores as a covariate to examine the effects of personalization and choice on learning outcomes. This analysis yielded a significant effect of experimental treatments on the learning measure ($F(4, 65) = 13.8$, $p < .0001$). Positive effect sizes were found for all conditions compared to the control, ranging from .67 for children exposed to fantasy conditions with no personalization over the control, to 3.01 for students with both fantasy conditions and personalization options over the control condition.

In general, the authors found that contextualization, personalization, and choice all produced dramatic increases, in students' motivation, depth of engagement in learning, the amount they learned in a fixed time period, and their perceived competence and levels of aspiration. Taken together, the findings provide strong evidence of the potentially powerful educational benefits that can result from the appropriate use of strategies designed to increase the intrinsic motivational appeal of learning activities for students.

***The Development Of Children's Writing Awareness And Performance Within A Generative/Evaluative Computerized Prompting Framework*. (1990).** Bonk, C., and Reynolds, T.

Bonk and Reynolds explored the use of a generative and evaluative computerized prompting framework to improve writing skills among middle school children. A sample of 164 children, grades six, seven, and eight, was divided into two groups: those with high writing skills and those with low writing skills. Children were then randomly assigned to the control or treatment group. The development of writing skills was explored in six different ways. First, mid-treatment and post-treatment writing quality data were compared between the treatment group (with a prompted condition) and the control group. Second, development was analyzed between three grade levels. Third, development was compared between high and low ability students. Fourth, development within an individual writing assignment was tracked and reevaluated through a keystroke mapping system. Fifth, possible internalization of prompts was examined. Finally,

children's writing gain scores over a ten-week period were compared. The treatment group received computer prompts, think-sheet scaffolds, and expert modeling of writing prompts, while the control group did not.

Dimensional and holistic assessment of written products, internalization of writing control strategies as measured by the Index of Writing Awareness (IWA), open-ended questions, and a prompt-sort task failed to show any advantage from treatment. Students' holistic scores, however, were significantly correlated with their awareness of writing skills. High-ability students performed significantly better than low-ability students on all the performance measures. For example, with holistic scores, at all grade levels, the high-achieving subgroups benefited from stronger treatment effects than did their lower-achieving peers (ES = .23 v. .91 for low- and high-achieving sixth graders; ES = .14 v. .63 for low- and high-achieving seventh graders; and .03 v. .46 for low- and high-achieving eighth graders). Similar results were found for generative and evaluation scores. Keystroke analysis indicated that the availability of prompts seemed to lower the number of changes students made during the writing process. In this study, child development was not only examined between groups and over time, but was explored between three grade levels. In most measures there was a significant main effect for grade that favored the older students. Differences in holistic performance, IWA performance, metacognitive guidance in writing, surface revisions, and repositioning within papers between grades six and seven were not found.

These findings suggest that a developmental change had occurred between grades six and seven, and that procedural assistance may be most appropriate in grade six. There seemed to be no significant positive effect of computer prompts on students' writing performance, although answers on the computer attitudes questionnaire indicated that the prompts helped the treatment group think of themselves as potential readers and accomplish more things than they could have accomplished just with pen and paper. Additionally, treatment group students produced fewer surface level changes when exposed to the computer intervention as the prompts caused the treatment subjects to scan their text more frequently than the control subjects.

***The Relationship Between Type Of Knowledge And Process Of Peer Collaboration In A Computer-Mediated Classroom*. (1993).** Oshima, J.

In this article, Oshima examined how students acquire their knowledge through peer collaboration in an educational environment called, "Computer Supported Intentional Learning Environment (CSILE)." CSILE is a hypertext database system that allows children to share their ideas with one another. It encourages students to organize their thoughts by linking charts and by labeling their texts to reflect corresponding thoughts. This helps them share information and keep track of thought processes. They can be engaged in higher-order thinking and in organizing their thoughts and those of their collaborators. Researchers have long been interested in determining how children interact with others in their collective activity to acquire new knowledge. Children can gain new strategies through peer collaboration by assisting each other or managing

complementary problem-solving roles. In this way, interpersonal discourse is found to facilitate individual knowledge acquisition. When children take on different roles of problem solving and help one another, they share their mental power and are capable of acquiring new knowledge that they cannot gain alone.

While research indicates that children benefit from their collective activities and learnings, this is not always the case (Azmita and Permutter 1990). Accessing how children succeed in gaining knowledge through peer collaboration can be accomplished by examining past performances that consider several hypothesized variables, such as students' internal ability and structure of groups. This is useful in the sense that fixed variables known before learning happens can be regulated in order to make learning successful.

Using a 3 x 5 experimental design, Oshima examined how twenty-seven fifth and sixth grade students created collective databases for a study of electricity. Their reported thoughts were shared with others via the database, and the others could easily comment on their thoughts. Thus, mediated by the database system, students were allowed to asynchronously collaborate with their friends. Based on the quality of their final constructed knowledge in the database, students were divided into three types of learners: (1) good theory builders, (2) average theory builders, and (3) poor theory builders. The processes of students' learning were compared among the types of learners based on the records of their computer manipulation.

The results showed that successful learners (1) planned their learning in the initial period and constantly produced their thoughts in the database; (2) spent much metacognition effort on their evidence but not on their theories; and (3) effectively used their personal resources in the classroom to construct their theories in the second half of learning. Oshima stated that this is a "tip-of-the-iceberg" examination of peer collaboration facilitated by computer use since children learn collectively with friends outside of traditional educational environments (i.e., while playing) and can co-construct their knowledge by interacting with friends in front of computers.

***Video Training As A Means Of Enhancing Self-Awareness In Problem Solving Among Young Children*. (1991).** Fireman, G., and Kose, G.

Fireman and Kose used an intervention pre- and posttest design to study conditions that facilitate children's self-regulation of problem solving activities. In two studies, children were trained to solve a three disc Towers of Hanoi problem. After training, they were asked to solve the problem, describe how they solved it, and perform a four-disc generalization task. In the first study, a total of 125 first through third graders were assigned to one control and three training conditions. In training, children (1) practiced solving the problem; (2) watched an adult model solve the problem in the most efficient way; or (3) viewed a video recording of their own prior performance in the problem. The effects of the training conditions on the number of moves to complete the problem were examined by a 4 (condition) X 3 (grade), two-way ANOVA.

Training conditions had differential effects on performance ($F(3, 124) = 16.57$, $p < 0.01$), although no main effect was found for grade, and no interaction effect was found. Scheffe's post hoc comparisons revealed that children in the control condition required more moves to solve the problem than did children in the experimental conditions. Training with a model hindered descriptions of solutions and performance of the generalization task, while the video training condition facilitated the regulation of problem solving activities. On the four-disc generalization tasks, there were significant main effects for condition ($F(3, 97) = 4.5$, $p < 0.01$) and grade ($F(2, 97) = 5.83$, $p <0.01$), but no interaction. Scheffe's post hoc analysis revealed that third graders required significantly fewer moves than first graders to solve the problem, and that subjects in the video condition required significantly fewer moves than did subjects in the model condition (both $p < 0.05$). Effect sizes for training conditions were not included in the article, but were calculated post hoc ($ES_{model} = 0.47$, $ES_{practice} = -0.11$, and $ES_{video} = -0.29$).

In the second study, a total of 60 first and second graders were placed in one of three video training conditions or a control condition. Children either viewed (1) a recording of their prior performance on the three disc problem; (2) a video; or (3) a video recording of a child model solving the problem in the most efficient way. Preliminary analyses revealed the superiority of triaging in which children viewed their own performance. Children in the practice and video conditions were more able to accurately describe the problem-solving steps than were children in the model and control groups. The video condition focused children's descriptions on action by providing active demonstrations in conjunction with their descriptions. Children in the video condition were most efficient in solving the problem.

***Increasing Reading And Communication Skills In Children With Autism Through An Interactive Multimedia Computer Program*. (1995).** Heimann, M., Nelson, K., Tjus, T., and Gillberg

Heimann and his colleagues examined the effect of using an interactive and child-initiated microcomputer program to teach reading and communication skills to children with learning disabilities. The sample included 30 children divided into three groups: (1) 11 children with autism; (2) nine children with mixed disabilities; and (3) 10 preschool children without disabilities. The children with autistic disorders included two boys and nine girls. The children with mixed disabilities comprised nine children (four boys, five girls), all with IQ scores of 70 or less. Many of these children had at least one motor or sensory impairment and two of the children were diagnosed with Down Syndrome. The remaining group consisted of 10 preschool children (two boys, eight girls) without diagnosed learning or sensory disabilities. The mental ages of the children in the sample varied from 5.8 years to 6.9 years, and all children received computer instruction supplementary to their regular reading and writing activities. Tests of reading and phonological (i.e., relating to sound and speech) development were carried out at the onset of the training, at the end, and at a follow-up evaluation. In addition, video

observations of the children's verbal and nonverbal communication were added at the start and the first posttest. Analysis focused on changes over time in observed means within each group. Standard parametric tests and nonparametric methods revealed similar results, so the authors included only the parametric data in the report.

The intervention consisted of 112 lessons aimed toward developing in a child a basic reading and writing vocabulary, and the ability to create simple sentences using this vocabulary. Using the Alpha program (a computer application constructed to facilitate language learning through multichannel—voice, animation, and video—feedback), each child was asked to create sentences by combining previously learned nouns with new verbs. The action of creating a simple sentence (i.e.,, a noun-verb-noun sequence, like The bear — jumped over — the horse) created an animation showing the action the child had described. Feedback was provided to participants during sentence construction. After having watched the animation, the child had to select the nouns and the verb to construct the sequence that described what the child had just seen. Once mastering a simpler level, the child was advanced to a more difficult set of tasks. At any given level, a child was judged to have reached mastery if achieving a score of at least 80 percent in the most difficult mode.

The children with autism increased both their word reading and their phonological awareness (i.e., sound synthesis) through the use of the program. Children with autism increased their mean scores from .03 to .14 ($t(8) = 2.85$, $p < .05$), and the children with mixed disabilities increased from .18 to .23 ($t(7) = 1.79$, $p < .06$). Similar gains were found for phonological awareness. In contrast, the preschool children without disabilities increased their scores regardless of the program. Analyses of the children's classroom behavior indicated that the intervention succeeded in stimulating verbal expressions among the children with autism and mixed disabilities. A significant increase in enjoyment was also noted for the children with autism. The gain in reading, demonstrated in the study, supported the hypothesis that computer-assisted instruction can have a specific impact on children with autism and other disabilities. Patterns of results observed for phonological skills also indicated a significant intervention effect for the combined results for children with disabilities.

Computer Intervention for Adolescent Children of Divorce. **(1995).** Barker, J., Brinkman, L., and Deardorff, M.

Barker, Brinkman and Deardorff explored the learning and effects of teens and parents participating together in an educational, computer-based divorce adjustment program. Sensitivity to the resistance of teenagers to therapy had prompted use of the computer as an intervention, as computers have many benefits over traditional didactic methods. Research shows that computer programs are effective for cognitive therapy (Clarke and Schoech 1984), human sexuality, drugs, and smoking interventions with children and adolescents. The researchers were interested to find if computer therapy could help teens and parents learn the skills necessary to cope with the stresses of divorce. They looked at 13 comparison child-mother pairs using a quasi-experimental design (pre- and post-

observations with no control comparison group). Their aim was to measure the learning of adolescents and their parents using the divorce adjustment computer program. The 13 comparison pairs—consisting of a child (aged 12-17) and a biological mother who had been divorced within the last three years and had not remarried—volunteered to participate in a computer intervention and follow-up study. Participants came to the computer lab, took the pretest, and played the computer game. The following week, the posttest was mailed, and one week later a ten-minute telephone interview with both the teen and the participating parent was conducted. Scores on parent and teen pre- and posttests were compared to measure changes in divorce adjustment knowledge. An analysis of individual questions missed was used to assess differences in principles learned.

While the authors report finding a slight increase in the mean posttest scores for both parents and teens, using the computer program did not statistically improve knowledge needed for divorce adjustment. The researchers state that this outcome may be a factor of a highly educated and motivated sample, as pretest scores were surprisingly high. The authors conclude that the sample had considerable mastery of divorce information prior to the study, and interviews revealed that many parents and children had had previous counseling in divorce adjustment prior to participating in the study. However, parents and teens reported an increase in understanding and communication and a decrease in conflicts related to the divorce adjustment process, as a result of using the computer intervention. The authors report that providing a choice of content prompts a hint at the correct answer, and presenting all the information necessary to correctly answer a question on the terminal screen all improved positive affective measures of the computer program. Participants also stated that the ability to confront real-world problems in a safe, simulated environment was an advantage facilitated by the computer, allowing them to practice alternative responses and receive feedback and reinforcement. Measure outcomes suggest that this computer intervention is an effective cognitive therapy. The study demonstrated increased understanding and communication between parents and teens and decreased conflicts in the divorce adjustment process, as a result of participating in a computer intervention.

PRINCIPLE FINDINGS FOR TECHNOLOGY-IMPACT ON CHILD DEVELOPMENT

This section discusses several of the important themes that emerged from the review of literature on empirical studies of the impact of technology on child development and well-being. Key findings from the 19 summarized articles are included, as are salient findings related to the important themes that came from the additional 22 studies we identified in the literature.

Technology Enhances Skills Development That Transfers to Other Aspects of Child Development

Several of the studies reviewed focused on the developmental gains for children who learn to use computers by becoming familiar with the LOGO programming language. In three studies (Cathcart 1990; Lehrer and Littlefield 1993; Lehrer, Randle, and Sancilio 1989) found that interventions with LOGO demonstrated medium to large effects on cognitive skills and helped to develop complex reasoning skills among children exposed to the intervention. There is also agreement that such interventions do not seem to benefit either attitude or knowledge acquisition. Littlefield, Delclos, Gransford, Clayton, and Franks (1989) found that exposure to LOGO benefited students who were exposed to mediated teaching, a pedagogical method effect in training to maximize benefits from technological applications. Both framing (the act of relating a specific set of behaviors to a broader framework of problem solving) and bridging (the act of relating processes that occur within one context to similar processes occurring elsewhere) were effective. This has as much to do with the teaching as with the students, as good LOGO teachers may implicitly engage in mediated teaching and make use of these features, thereby improving their students' performances. The methods used to teach LOGO significantly affect what is learned (and therefore the skills that are available for transfer).

While LOGO seems to be beneficial in developing skills for learning that transfer to other aspects of child development, not all children realized important gains from learning to program using the language. For example, Wenglinsky and colleagues (1998) found that the use of computers to teach lower-order thinking skills is negatively related to academic achievement. Computers seem especially powerful for teaching science curricula at higher grade levels. For example, computer science simulations can aid high school students in substantially increasing their problem-solving skills (Rivers and Vockell 1987). Science education focuses on developing students' skills to critically evaluate scientific data. Microcomputer-based learnings can assist students in developing a more complete understanding of graphs that depict collected data. Furthermore, students can become more critical of the data presented on graphs upon using microcomputer-based learnings (Nachmias and Linn 1987).

Technology Games Support Spatial Skills

Much attention has been paid to the potential negative effects of some entertainment media in recent years that suggests that violence depicted in video games transfers to child behaviors. The studies reviewed for this paper indicated a very different effect for child development, especially in the area of spatial skill development. Subrahmanyam and Greenfield (1994) found that video game practice led to significant improvement in dynamic spatial skills in children, and video games can provide a cultural push that sends both boys and girls down the developmental path of spatial skill development. Fifth graders seemed to be at a developmental age where spatial abilities were emerging and developing and were therefore more susceptible to the effects of training than were older children. Furthermore, for older children, computers and video games can be useful tools in activities and jobs that require high levels of spatial skills. With computers fast becoming the dominant technology of the day, video games may serve as an informal technique for equipping girls and women with the skills and motivation they need to

ensure that they are not left behind in the future. Okagaki and Frensch (1994) found that those wishing to capitalize on the motivational aspect of video games for spatial skills training will need to find or develop games that are similar to the actual contexts in which the spatial skills will eventually be used. They also found that spatially oriented video games have potential to improve adolescents' mental rotation and spatial visualization skills. Wenglinsky and colleagues (1998) found that for younger children the use of computers for learning games was positively related to academic achievement.

Other articles reviewed for this paper indicated that frequency of video game use had slightly negative correlations with boys' sociocognitive abilities, such as empathy, cognitive complexity, and cognitive abstractness. The frequency of computer use, for such things as word processing or programming, had few correlations to sociocognitive abilities (Sakamoto 1994). Silvern and Williamson (1987) found that video games are no more likely than certain television programs to cause negative effects in terms of aggressive behavior. Despite the increased concerns of video games causing heightened aggression in children, a study conducted by comparing "levels of aggressive, imaginative, and prosocial behavior in young children, after video game play, with levels of the same behaviors after television viewing and at baseline, found that violent video games cause similar levels of arousal in children as do violent television cartoons" (460). Yet, in another study examining the effects of playing videogames on children's aggressive behavior, Schutte and colleagues (1988) compared children's aggression after playing nonviolent video games versus violent video games. Their findings indicated that, consistent with modeling and reward conditioning theories, children display behavior similar to behavior displayed during the video game. Furthermore, this study supported the hypothesis that aggressive behavior was more likely to occur following the playing of a violent videogame. Finally, Cearone (1998) found that playing video games could facilitate language development in autistic children.

Technology Facilitates Collaboration

Several of the reviewed studies indicated that technology can help facilitate the development of planning and collaboration for children of all ages. Barbieri and Light (1992), and Oshima (1993), found that computers can facilitate the complex functioning task of advanced planning, that is, planning out tasks prior to conducting them. They found that such planning tasks continue throughout activities, and that the use of technology facilitates collaboration and assists in transferring such learning benefits to other life skills. Such collaborative, collective activities in the late period of learning facilitates student knowledge acquisition beyond their individual work in the initial period of learning.

Both metacognitive and collective activities in peer collaboration were important for students to succeed in their learning. Processes of learning were critically different among students who acquire different types of knowledge. Chang and colleagues (1998) found that contextual factors make a difference in child development. These factors included enthusiastic and dedicated adults who help to facilitate child development with

their guidance and instruction, high expectations for students who get advantages (such as exposure to technologies), and involving parents in the education of their children. Technology-facilitated factors included increased communication between care providers, children, and parents; increased collaboration among children in their learning; increased collaboration between care providers and teachers; additional opportunities to write and edit; and additional opportunities to undertake multimedia-authoring projects. McFarlane and Friedler (1998) found that students enjoyed working collaboratively, passing the computer to one another to share work.

Technology Strengthens Communication

Another important theme to come out of the reviewed articles was that of the advantage technology can deliver in terms of enhancing communication in educational and developmental processes. Barker, Brinkman, and Deardorff (1995) found that both parents and teens could understand the other's perspectives and engage in open and direct communication, given that the computer provided a nonjudgmental, non-emotional interface. Their study also revealed that reading about case studies (as presented by the computer) allowed participants to objectively look at their situations. Here the computer is a delivery system for the intervention, but one that de-emotionalizes the topic area and serves as an objective interpreter of participant responses.

Wenglinsky and colleagues (1998) found that communication capabilities afforded by email, online discussion groups, and listservs mean that the teachers, students, and parents can engage in conversations more regularly and more easily than has ever been possible in the past. They suggested that more data needed to be collected on exactly how teachers and students are using the network to communicate with each other. Technology increases students' access to teachers by expanding the time they can seek help from their instructors. Student requests for help with assignments were frequent when they were connected to teachers with the Internet or other communication networks. This advantage is not limited to children but extends to teachers and parents as well. Teachers use the Internet and other network communications to communicate regularly with parents, and parents communicate with teachers about their children's progress and issues of concern. As a tool for supporting communication among teachers, network technologies have shown much potential in this way. In support of these findings, Honey and Henriquez (1996) found that teachers engaged in conversations about curriculum issues and ideas for collaborative projects. They also suggested that teachers who worked closely with students on their writing skills saw marked improvements in the students' ability to write.

McFarlane and Friedler (1998) observed knowledge exchange between teachers and students; that is, teachers learned applications from the students and students were given opportunities to lead the class. In a study designed to record the personal and educational interactions of disadvantaged families when given unrestricted access to online services, Bier, Gallo and colleagues (1996) found that parents indicated a positive change in their self-perception, feelings of confidence, and learning ability. Parents also developed

personal relationships on the Internet, which provided friendship, companionship, therapeutic conversation, and support. Finally, research testing the effectiveness of using LAN technology, especially email, to develop written communication skills in deaf students indicated that consistent and frequent use of LAN technologies, in a variety of activities, can improve communicative effectiveness and connectedness of writing (Moeller, Bell, and Reich 1993).

Technology Enhances Student and Teacher Efficiency and Motivation

Technology, including computers and other advanced technologies, increases children's motivation for learning and exploring other developmental skills. Fireman and Kose (1991) found that technology can be used to expand children's awareness of their successes and weaknesses in problem solving, and that such technology need not be state-of-the-art to be effective. Using relatively low-end technology (video) in training children to problem-solve improves efficiency of task completion outcomes. Wenglinsky and colleagues (1998) found that students who make use of word processing and desktop publishing software write more often than their peers who do not. Chang and colleagues (1998) found that using software increases students' interest in writing, and that web authoring projects support and enrich children's learning agendas. Children using such applications realized developmental gains in mastery of content knowledge; gathering, interpreting, and synthesizing information; knowledge of design principles; awareness of audience; technical complexity; ability to collaborate; and critique and revision.

McFarlane and Friedler (1998) found that classes using portable computers were behind in the curriculum because students were more aware of shortcomings in their work and taking more time to review, edit, and improve their work. Rozik-Rosen and Atlas (1994) found that program coordinators believed aims to help students feel connected to the world and stay connected to healthy parts of their lives could be accomplished through computer use. In a study that looked at the negative effect of lack of motivation, Littleton and colleagues (1993) found that levels of engagement with computer-based related tasks may affect performance. They found that girls, who found one software program less enjoyable and less motivating than another, performed lower on the task related to the less-enjoyable program.

Technology Supports Multiple Teaching Techniques

Across all of the studies reviewed, it became clear that technology alone is not a cure-all for all child development challenges and potential gains. How technology is applied—and the factors related to that application—are critically important to understand. For example, Cordova and Lepper (1996), in another motivation study, showed that students exposed to motivationally embellished activities displayed higher levels of intrinsic motivation, became more deeply involved in the activities of learning, attempted to use more complex operations, and learned more in a fixed period of time. They demonstrated higher subsequent levels of aspiration and feelings of perceived

competence than their counterparts who were exposed to unembellished versions of these same activities. The authors suggested, however, that there is no reason to believe their findings are dependent on the use of the computer. Although, they do contend that evidence elsewhere showed that the introduction of computers into the classroom has provided a truly unprecedented opportunity for the increased individualization of instruction. Heimann, Nelson, Tjus, and Gillberg (1995) showed that motivating multimedia programs shows promise in stimulating reading and communication in children with various developmental disabilities. Such interventions, however, must be individually based and include both detailed planning and monitoring from teachers, parents, and other adults.

Follansbee and colleagues (1996) found that curriculum and ongoing teacher supports, combined with online use, have positive effects on student learning and on teacher practice. They state that evaluations of student projects offer the most significant support for the importance of a curriculum that can adapt current practices to the inclusion of online activities and resources. Duffy and Barowy's (1995) study showed that computer-facilitated learning is not likely to be successful without proper attention paid to curricular elements and appropriate levels of teacher (or supervisory) interaction. This was supported by Songer (1996) who stated that lessons and curricula must be designed to incorporate the Internet and computers into the learning environment so students can take advantage of particular features of Internet-based classroom learning. She contends that computer and Internet technology does not remove challenges encountered by teachers, instructors, or parents in facilitating learning.

Wenglinsky and colleagues (1998) discussed perceived inequities of technology in terms of child development. They state, the greatest inequities did not lie in how often computers were used (access issues), but in how they were used. For example, they found that Black fourth graders reported more frequent school computer use than white fourth graders. Black students, however, were less likely to be exposed to higher-order uses of computers and more likely to be exposed to lower-order uses than were white students. Similarly, poor, urban and rural students were less likely to be exposed to higher-order uses than non-poor and suburban students. To this end, they suggest that technology can matter in education and child development, but its impact depends on how it is used. While they find that the frequency of home computer use is positively related to academic achievement, they clearly state that children with increased access to technology tools (Internet, word processing, spreadsheet, and database programs) do significantly better in school than their peers without access to the same tools.

Finally, Wenglinsky and colleagues (1998) found that computers could have positive effects on test outcomes and educational achievement. They found that eighth graders whose teachers used computers mostly for simulations and applications (usually associated with higher order thinking) performed better on the national progress and achievement tests than students whose teachers did not. Fourth graders whose teachers used computers for math and learning games scored higher than those in classrooms where the teacher did not. In both grades, those students whose teachers had professional development in computers outperformed students whose teachers did not.

Technology is Customizable to Developmental Age and Stage

One other important theme that emerged from the reviewed articles was that achievement, advantage, and child development by age was related to the use of and exposure to technologies. Wenglinsky and colleagues (1998) found that the size of the relationships between the various positive uses of technology and academic achievement was negligible for fourth graders but substantial for eighth graders. For the older students, professional development and using computers were each associated with more than a one-third of a grade level increase in higher-order thinking skills. In the middle school years, writing was one area where depth of access to technology was making a difference in students' performance. Calvert (1994) conducted a study looking at developmental differences in children's production and recall of computer-presented information and found that there is a developmental shift from kindergarten to second grade in the way children recall information. More specifically, kindergarteners relied more on perceptually salient features than did second graders. That is, kindergarteners recalled information better when it was presented in action instead of still frames. By second grade, action did not affect recall. Rozik-Rosen and Atlas (1994) stated that a program established in 1990 called TLALIM used computers to enable sick children, who were absent from school for long periods of time, to return to school and continue their studies without gaps in learning.

CONCLUSIONS

This review of empirical studies of technology's impact on aspects of child development and well-being, along with its companion paper reviewing recent additions to the meta-analysis literature, posed three research questions:

- What impact does technology used in educational settings have on child development?
- Which uses of technology hold the greatest promise for improving child well-being outcomes?
- What future research is needed to understand the impact of technology on children according to cognitive, social, emotional, and physical perspectives?

This review reveals an evolution in thinking about technology and child development as a research question in the scientific community. As stated in the companion paper, determining whether one technology can out-perform another is less important than understanding the mix of technology, content, and pedagogy that affects learning positively. The "horse-race" questions ("Does technology enhance child development?" and "Do computers enhance learning?") have been answered in the affirmative. Technology is beneficial to child development, and in turn, enhances child well-being. It has been widely established that for the most fundamental levels of child development and learning, technology in the role of the teacher (drill-and-practice) is effective. While

overall there is currently less understanding of the higher-order gains from technology, articles reviewed for this paper suggest that technology is especially effective in delivering desired outcomes for such higher-ordered learning objectives.

The evolution of the research in this area now leads us to understanding which uses of technologies hold promise for enhancing child development and child well-being. This question, too, is answered in this review. Technology offers the greatest benefit when used for enrichment and as a tool that leads to the development of higher level information-seeking and problem-solving skills, although not at the exclusion of lower-order cognitive skills (i.e., rote learning). When computer access is sufficient and computer technology is employed appropriately, child development is improved. But it has become increasingly clear that learning *from* technology does not hold the same promise as learning *with* technology. Learning with technology to facilitate critical thinking and higher-order learning allows children to use technological tools to analyze the world, access and interpret information, and represent what they know to others. Cognitive tools are learner-centered and controlled, and as such, facilitate learner-centered child development, again positively impacting child well-being.

Given these findings, these conclusions should be viewed within the context of potential limitations. Our search criteria focused on literature examining the efficacy and effectiveness, rather than the negative outcomes of computer applications. As a result, the results were generally positive in nature because the "negative" findings were limited to lack of evidence for a positive effect emerged. Another limitation is publication bias, which is inherent in research syntheses. We attempted to mitigate that bias to the extent possible by not limiting our searches to articles in peer reviewed research alone.

In considering what future research is needed to understand the impact of technology on children according to cognitive, social, emotional, and physical perspectives, this review offers guidance. Researchers need to redouble efforts to determine what factors influence the successful use of technology and how to apply them to child developmental stages and learning environments. The evidence is clear: when properly used, computers serve as important tools for improving the overall learning environment in schools. What now needs to be addressed in the research is achieving an understanding of the variety of roles technology plays in influencing child development. This report indicates that there exist differential impacts for technologies depending on what role in child development or learning the technology plays. The variety of roles (i.e., teacher, tool, supplemental learning device, etc.) indicates a variety of opportunities for research.

It is important to note that technology itself is not pedagogy for child development. Adults who care for, and care about, the development of children will benefit from increased training with and commitment to technological applications in early child development, and indeed throughout the education of children. One must remember, however, that technological solutions and advancements do not exist or occur in a vacuum. Sound learning theory, child development theory, and teaching techniques that incorporate technology as a learning asset need to be developed, tested, and studied in conjunction with changing and evolving technologies.

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