DOCUMENT RESUME

ED 371 726 IR 016 680

AUTHOR	Sivin-Kachala, Jay; Bialo, Ellen R.
TITLE	Report on the Effectiveness of Technology in Schools, 1990-1994.
INSTITUTION	Interactive Educational Systems Design, Inc., New York, NY.
SPONS AGENCY	Software Publishers Association, Washington, DC.
PUB DATE	94
NOTE	47p.
PUB TYPE	Information Analyses (070) -- Reports - Research/Technical (143)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	Academic Achievement; Comparative Analysis; Computer Software Development; *Computer Uses in Education; Courseware; *Educational Research; *Educational Technology; Elementary Secondary Education; *Instructional Effectiveness; Intermode Differences; Literature Reviews; Student Attitudes; Teacher Attitudes; Teacher Student Relationship
IDENTIFIERS	Learning Environments

ABSTRACT

This report summarizes the educational technology research conducted from 1990 through 1994. It is based on 133 research reviews and reports on original research projects from both published and unpublished sources. This research varied in methodology: some studies used a technique for synthesizing and analyzing data from many different studies; some compared the use of technology to traditional instructional methods; some compared the use of technology under different learning conditions; and some utilized classroom observation. The report is divided into three sections: (1) "Effects of Technology on Student Achievement"; (2) "Effects of Technology on Student Self-Concept and Attitudes about Learning"; and (3) "Effects of Technology on Interactions Involving Teachers and Students in the Learning Environment." A list of conclusions drawn from the analysis is included, as well as a bibliography of the research cited. (Contains 170 references.) (JLB)

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[redacted] 1994

REPORT ON
The Effectiveness of Technology in Schools 1990-1994

CONDUCTED BY: Interactive Educational Systems Design, New York, NY
COMMISSIONED BY: Software Publishers Association, Washington, DC

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Special thanks to the following people who contributed to this report:

Charlene Blohm, *Blohm and Associates*
Carole Cotton, *CCA Consulting*
Jennifer House, *Apple Computer, Inc.*

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Report on the Effectiveness of Technology in Schools, 1990-1994: Executive Summary

In the 1980s, the United States experienced dramatic growth in the use of computer-based technology for instructional purposes. According to the US Congress, Office of Technology Assessment, the percentage of schools with one or more computers grew from approximately 18 percent in 1981 to 95 percent in 1987.[1] It is estimated that as of the 1992-1993 school year, more than 4.4 million computers were installed in the nation's more than 17,000 school districts.[2]

During the 1980s, computer technology has generally been credited with motivating students, aiding instruction for special needs students, improving student attitudes toward learning, and motivating teachers and freeing them from some routine instructional tasks, enabling them to better utilize their time.

In 1990, the Software Publishers Association published its first *Report on the Effectiveness of Microcomputers in Schools.* In that report, numerous research studies supporting the use of technology as a valuable tool for learning were described. These studies showed that the use of technology as a learning tool can make a measurable difference in student achievement, attitudes and interaction with teachers and other students. The evidence suggested that positive effects of technology were dependent upon the subject area, characteristics of the student population, the teacher's role, how students are grouped, the design of the software, and the level of access to technology. Since then, research documenting the effectiveness of educational technology has continued to grow.

GOAL OF THIS REPORT

This report, commissioned by the Software Publishers Association and conducted by an independent educational technology consulting firm, Interactive Educational Systems Design, Inc., summarizes the educational technology research conducted from 1990 through 1994.

This report is based on 133 research reviews and reports on original research projects, from both published and unpublished sources. Of these 133 studies, 58 were published in professional journals, and 24 were doctoral dissertations.

These 133 studies were chosen from an original set of over 700. Studies were not included for a variety of reasons. Some were weak in methodology (e.g., comparisons of a computer-based instructional treatment to no alternative treatment). Some were narrow, reporting on a single commercial software product. Some addressed topics not of concern in this report (e.g., critiques of typical research methods; research on the attitudes of student teachers; research on the design of the physical layout of technology-rich classrooms).

The research examined varies in methodology. Some studies use a technique for synthesizing and analyzing data from many different studies. Some studies compare the use of technology to traditional instructional methods. Others compare different software designs or the use of technology under different learning environment conditions. Still others are based on classroom observation and surveys of teachers and students.

The report is divided into three sections:

- Effects of technology on student achievement
- Effects of technology on student self-concept and attitudes about learning
- Effects of technology on interactions involving teachers and students in the learning environment

Also included is a bibliography of the research cited.

CONCLUSIONS

Technology is making a significant positive impact in education. Important findings in these studies include:

- **Educational technology has demonstrated a significant positive effect on achievement.** Positive effects have been found for all major subject areas, in preschool through higher education, and for both regular education and special needs students. **Evidence suggests that interactive video is especially effective when the skills and concepts to be learned have a visual component and when the software incorporates a research-based instructional design.**

- **Educational technology has been found to have positive effects on student attitudes toward learning and on student self-concept.** Students felt more successful in school, were more motivated to learn and had increased self-confidence and self-esteem when using computer-based instruction. This was particularly true when the technology allowed learners to control their own learning.

- **The level of effectiveness of educational technology is influenced by the specific student population, the software design, the teacher's role, how the students are grouped, and the level of student access to the technology.**

- **Specific characteristics of the learning environment help to maximize the benefits of educational technology:**

  1. District-level involvement and the leadership of a school-level computer coordinator are key factors in developing a school environment conducive to effective use of technology.

  2. Teachers are more effective after receiving extensive training in the integration of technology with the curriculum.

  3. Exemplary computer-using teachers benefit from a social network of other computer-using teachers at their school.

  4. Exemplary computer-using teachers typically have smaller class sizes and more funds available for software acquisition.

  5. Teachers should carefully plan, and actively participate in, learning activities that incorporate tool software.

  6. Teachers should offer students self-directed learning experiences and activities that encourage self-expression.

  7. Students benefit from personal interaction among class members.

- **University and in-service teacher training provides teachers with greater comfort in using computers, an increase in the desire to use computers and an understanding of how to integrate software into the classroom curriculum.**

- **Introducing technology into the learning environment has been shown to make learning more student-centered, to encourage cooperative learning, and to stimulate increased teacher/student interaction.**

- **Positive changes in the learning environment brought about by technology are more evolutionary than revolutionary.** These changes occur over a period of years, as teachers become more experienced with technology.

- **Courses for which computer-based networks were used increased student-student and student-teacher interaction, increased student-teacher interaction with lower-performing students, and did not decrease the traditional forms of communication used.**

- **Greater student cooperation and sharing and helping behaviors occurred when students used computer-based learning that had students compete against the computer rather than against each other.**

- **Small group collaboration on computer is especially effective when students have received training in the collaborative process.**

This report provides software developers and publishers with research that will enable them to improve educational technology so that it continues to have a significant positive impact on student achievement, self-concept and attitudes, and on the interactions in the learning environment for students of all ages, capabilities, socio-economic backgrounds, and areas of interest.

Section 1: Effects of Technology on Student Achievement.

Original research reports and reviews of educational research published between 1990 and 1994 confirm that microcomputers and other educational technologies have beneficial effects on student achievement. Research indicates the effectiveness of using technology to support instruction in a wide variety of curriculum areas, including: reading, writing, spelling, mathematics, social studies, science, psychology, accounting, music appreciation, and cognitive skill development.[3]

A growing body of research shows, however, that the effectiveness of educational technology depends on a match between the goals of instruction, characteristics of the learners, the design of the software, and technology implementation decisions made by teachers.

In this section, we set out to accomplish three things: (1) report on recent studies in which technology-based instruction is compared to other instructional methods; (2) explore several well-researched curriculum areas in depth; and (3) review research that relates student achievement to learner characteristics, software design, more recent technologies, and instructional decisions concerning technology implementation.

COMPARISON STUDIES

Several recent studies present meta-analyses of the effects of technology-based instruction in comparison with other instructional treatments (usually traditional methods). *Meta-analysis* is a method of assessing the effects of technology-based instruction across many different studies, using a common measurement scale, called *effect size* (ES). An ES of 0.3 can be interpreted to mean that the technology-based instruction is 30 percent more effective than the control group instruction.

> *...in terms of grade-equivalent units [an ES of 0.3 is interpreted to mean] approximately 3 months additional gain.*[4]

Thus, in three years, an instructional treatment with an ES of 0.3 per year would result in an additional gain of almost 1 year.

According to Kulik and Kulik,[5] an ES of 0.3 is considered to be a "moderate but significant effect." In their meta-analysis of 254 controlled evaluation studies covering students from kindergarten through higher education, they found that computer-based instruction (CBI) had an average ES of 0.3. Where differences in achievement were statistically significant, the difference favored CBI in 94 percent of the cases.

Ryan[6] conducted a meta-analysis of 40 comparative studies focusing on the use of computers in elementary schools. She calculated an average ES of 0.309. Ryan found that the amount of technology-related teacher training was significantly related to the achievement of students receiving CBI. Students of teachers with more than 10 hours of training significantly outperformed students of teachers with 5 or fewer training hours. (Survey research by Cates, McNaull and Gardner[7] lends support for the importance of teacher training. Compared to teachers with less training, teachers with more than 3 credit hours of university coursework and more than 3 contact hours of inservice training rated themselves significantly higher on scales of computer expertise and computer comfort, had "significantly higher opinions of the usefulness of software," and reported significantly greater use of computers in the classroom.)

In his meta-analysis of the effects of using a word processor as an instructional tool, Bangert-Drowns[8] found an average ES of 0.27 for improvement of writing quality. He characterized this effect, based on 20 studies, as small but statistically significant. However, nine studies that focused on word processing in the context of remedial writing instruction yielded an average ES of 0.49, a significantly larger effect.

Two meta-analyses suggest the instructional value of interactive video (IV). In Fletcher's[9] meta-analysis of 47 studies of higher education and miltary and industrial training, it was found that students receiving instruction via IV had achievement scores that averaged 0.50 standard deviations above the scores of students receiving conventional instructional. McNeil and Nelson[10] completed a meta-analysis of research on the cognitive achievement effects of IV, resulting in an overall ES of 0.502. They found significantly higher results when teachers used IV as a supplement to traditional instruction than when IV was used to replace traditional instruction.

These meta-analyses confirm that technology has a positive effect on student achievement. The studies also underscore the importance of the teacher's role in the effective use of educational technology.

CURRICULUM AREAS AND STUDENT ACHIEVEMENT

Reading and Writing

Reading and writing have been frequent focuses of educational technology research in recent years. Highlights are presented as follows.

Reading. A tutorial and practice program called *Daisy Quest* was developed by Foster, Erickson, Foster, and Torgeson to increase young children's phonological awareness.[11] Phonological awareness is defined as "one's sensitivity to, or explicit awareness of" the structure of sounds in one's language. The developers view the value of the program as helping "children understand the alphabetic principle during the early stages of reading instruction." The majority of practice in *Daisy Quest* is in recognizing identical sounds or sound combinations across words (e.g., the initial sound in "fish" and "fat"; the final sound combination in "dog" and "log"). The program uses high-quality digitized speech.

In two separate studies and five different measures of phonological awareness, the computer-based approach was found to be significantly more effective than regular instruction.[12] The average ES of 1.05 is considered significant.

Reading and Writing. Green[13] explored the effects of three different approaches to writing instruction on achievement in reading for inner-city, Mexican-American third-graders. A writing process approach with word processing resulted in significantly higher reading achievement than a similar approach without word processing or a grammar-oriented approach to writing.

Writing. Several researchers have found that student use of word processing software results in higher quality writing. Such results were reported for regular education students,[14] English as a Second Language (ESL) students,[15] and for special needs students.[16]

Bair17 found that emotionally disturbed students in grades 6-12 who used computers demonstrated superior performance in writing maturity, reduction in spelling errors, and length of writing. Silver and Repa[18] found that ESL high school students who used word processing software in combination with a developmental learning sequence on the writing process evidenced higher quality writing than students receiving equivalent instructional without word processing. Owston, Murphy, and Wideman19 found that regular eighth graders' computer-written papers were rated significantly higher in quality than handwritten papers for overall writing competence, focus/organization, support, and mechanics. They note, however, that

> *...students appear to bring their own personal style of working to the word processing environment; computers do not of themselves dramatically change student writing style. Instead, they appear to facilitate whatever level of editing the user wishes to engage in.*

It was determined in a recent study by Zellermayer, Salomon, Globerson, and Givon[20] that **a computer writing tool that automatically provides ongoing, unsolicited guidance throughout the stages of the writing process improved the quality of student writing — even after the support structure was removed.** Students who had used this tool expended more mental effort and demonstrated significantly greater writing improvement than students who had used a tool that provided guidance only upon request, or students who had practiced writing using only word processing software.

Several studies support the notion that teacher decisions are critical in effective writing instruction using a word processor. For example, Beyer[21] compared a process approach to writing with regular word processing to writing instruction with only limited access to computers. The process approach with word processing included daily teacher use of the process approach to writing; student use of computers on a rotating basis to work on writing assignments; daily teacher use of a short writing lesson; teacher-student writing conferences; and ongoing teacher monitoring of student computer use and progress with writing assignments. Students using this approach significantly outperformed the group who had limited computer access on organization, development, standard writing conventions, and overall writing quality.

A 1991 study by Dailey[22] suggests that assigning high school students to small cooperative groups when writing with a word processor is superior to having them write on computers individually. The students in small groups of three were preassigned roles of recorder, keyboarder, or checker. Students working independently received whole class writing instruction before proceeding to the computer. Results indicated significant differences in favor of the small groups across the stages of the writing process.

Valeri-Gold and Deming,[23] after reviewing research on computers and basic writing instruction, aptly conclude:

> *...the most effective utilization of computer software in the basic writing classroom combines the best of writing instruction theory with a creative use of computer technology. Only well-informed, trained and caring composition instructors will help to bridge the gap between technology and humanity.*

In her review of research on writing with word processors, Snyder[24] found that **when a sound model of teaching writing is implemented, students using word processing have demonstrated higher levels of achievement than equivalent students writing without word processing.**

Spelling

Two studies identified by Anderson-Inman[25] suggest that keyboarding and keyboarding software can be used to improve spelling for low performing students. In one study,[26] students worked with keyboarding software that allowed teachers to enter the words to be used in typing drills; students used it to practice spelling words and take spelling tests. In the other study,[27] students practiced spelling using laminated keyboards not attached to computers; McClendon found that significant improvement in spelling scores resulted from a combination of keyboard-based practice and direct spelling instruction.

Mathematics

Several recent studies compared instruction in mathematics using technology to instruction using traditional methods.

Two of the studies were designed so that instructional time for the experimental and control groups was approximately the same. Reglin[28] focused on a seminar on mathematics skills, in preparation for an exam required for admission to teacher education programs. One group of students received nine hours of classroom instruction and nine hours of computer-assisted instruction (CAI); the other group received 18 hours of classroom instruction. Students in the classroom instruction-plus-CAI group showed significantly higher achievement gains than the students in the classroom instruction-only group. In another study, third and fifth graders received either CAI (*Milliken Math Sequences*) or traditional math instruction for 71 days.[29] At both grade levels, students receiving CAI scored significantly higher than students receiving traditional instruction on a test of basic math skills, as well as on an assessment of computer literacy. CAI was rated as having greater cost utility. **Since these two studies were controlled for time spent on instruction, their results suggest that the computer experience, not merely time-on-task, accounts for the differences in student achievement.**

Two studies by researchers at the Stevens Institute of Technology[30] demonstrated the positive effects of commercially-available high school mathematics software on retention (i.e., performance on a delayed post-test). In one study, each student received instruction for two geometry topics, one with supplemental software and one without. One group used software for the first topic, and the other group used software for the second topic. For retention, student performance was significantly better when instruction included software. In the other study, two groups of students were compared. One received instruction that included supplemental software, and the other group did not use software. Once again, the group using software demonstrated significantly better retention (70 percent better) than the group who did not use software. **The researchers point to the technology experience of the teachers in the computer-mediated treatments as a critical factor.** They note that the teachers "had been part of a computer-mediated education development project for more than two years."

Funkhouser found that high school algebra and geometry students who used commercially-available problem solving software scored significantly higher on tests of mathematics content than a comparable group of students who did not use the software. The students using the software also made significant gains in problem solving ability.[31]

In a study by Alexander,[32] college algebra students who used software designed "to aid in the instruction of functions using concrete visualization" plus a graphing calculator significantly outperformed students receiving conventional instruction in their "understanding of the concept of functions...and in mathematical modeling." **The results in this study suggest the power of the computer to provide concrete visual support for the learning of abstract concepts.**

Two studies by the Cognition and Technology Group at Vanderbilt University[33] explored the effectiveness of *The Adventures of Jasper Woodbury*, a video series focusing on mathematical problem solving.

> *[The video series is] designed to promote problem posing, problem solving, reasoning, and effective communication. Each adventure is a 15-20 minute story. At the end of each story, the major character (or group of characters) is faced with a challenge that the students in the classroom must solve before they are allowed to see how the movie characters solved the challenge.*

Students in Jasper classes outperformed students receiving traditional math instruction in solving one-step, two-step, and multi-step word problems. Jasper students demonstrated greater skill in planning for problem solving and generating "the subgoals necessary to achieve a larger goal." Jasper is a good example of software that engages students in the construction of their own knowledge and that anchors instruction in the context of meaningful, real-world problems.

Science

Two recent studies demonstrated the advantages of combining hands-on science instruction with tool and simulation software.

Gardner, Simmons, and Simpson[34] found evidence of the benefits of hands-on meteorology activities combined with content-specific tool software. Three groups of third-graders were compared: one group receiving hands-on activities with software; one receiving hands-on activities without software; and one receiving traditional classroom instruction. The hands-on activities with software group siginficantly outperformed the hands-on activities only group on a test of meteorology knowledge. Both of these groups scored signficantly higher than the students receiving traditional instruction.

Lazarowitz and Huppert[35] had similar results with high school biology students. One group received classroom-laboratory instruction that included use of a software program that combined simulated experiments and laboratory analysis tools. The other group received classroom-laboratory instruction only. The group using the software demonstrated significantly higher achievement in content knowledge and in the science process skills of graph communication, data interpretation, and controlling variables.

English as a Second Language (ESL)

Liu[36] found that hypermedia software designed to permit exploration of semantic networks can help international college and graduate students (non-native English speakers) in English vocabulary development. A semantic network is the web of interrelated concepts that represents one's depth of understanding of any given concept. For example, a semantic network for the concept *lawyer* could include *trial, judge, defendent, jury,* etc. Students who used the software demonstrated significant gains in vocabulary knowledge.

Logo and Other Programming Languages

The effects of Logo and other computer programming languages on student cognitive abilities continue to be a focus of research.

<u>Meta-analyses</u>. In two meta-analyses of the effects of computer programming on cognitive perfor-

mance (e.g., "reasoning skills, logical thinking and planning skills, and general problem solving skills"), programming had an average ES of 0.41 when compared with non-computer instructional methods.[37] This suggests that the "learning of programming can positively enhance students' cognitive performance."

Logo and creativity. Clements[38] compared Logo's effect on the creativity of eight-year-olds with the effects of other "creative" uses of computers and a scheduled school "activity period" for special interest activities.

As part of the Logo treatment, students were introduced to basic Logo commands and presented with simple "challenges." Later the concept of "procedural thinking" was introduced and encouraged as students engaged in programming. Component processes of procedural thinking were given human-like identities, so that the students could better relate to them and remember them. Students chose their own projects and were prompted to "reflect on their use of componential processes."

The other computer group wrote compositions (using an integrated prewriting, word processing, and editing package) and created drawings (using graphics software). As with the Logo group, there was a focus on processes, student selection of writing and drawing projects, and "interpersonal interaction with peers and (the same) teacher."

After 25 weeks, students in both computer groups significantly outscored the non-computer group in verbal creativity. The Logo group demonstrated significantly higher performance in figural creativity than either of the other groups. It is important to note that these positive effects were the results of both a computer environment and a teacher-dependent instructional environment.

Logo and problem solving. **A group of researchers found that pairs of students engaging in Logo activities achieved significantly higher gains in metacognitive processing than pairs of students who used CAI problem-solving programs.[39]** Metacognitive processes are those related to planning and evaluating one's thinking while solving problems. The research suggests two characteristics of Logo that may account for its effectiveness: (1) it stimulates students to make their own rules; and (2) its open-ended structure allows students to successfully resolve their cognitive conflicts. Logo's ability to stimulate resolution of cognitive conflicts based on "ideas relevant to the problem's solution" has been confirmed in subsequent research.[40] Researchers found evidence that cognitively-based resolution of cognitive conflicts helps promote higher-order thinking.

Logo and geometry concepts. **Two recent studies demonstrated that the use of Logo had a significant effect on students' understanding of basic geometry concepts.** In one study, fourth graders who used Logo developed "mathematically sophisticated and elaborate ideas of angle, angle size, and rotation."[41] In the other study, seventh and eighth graders who used Logo significantly outscored students who received traditional math instruction on a test of the concepts of point, ray, line, and line segment.[42] The Logo students also demonstrated superior conceptualization of these geometry concepts in interviews.

Keep in mind that the Logo-based instruction students received in all of these studies required the active participation of Logo teachers. The achievement effects are the result of an interaction between the software's characteristics and the classroom environment teachers create.

When considered together, the 23 studies described above suggest that the use of software and technology helps students to achieve in a variety of curriculum areas.

SPECIAL POPULATIONS AND STUDENT ACHIEVEMENT

Early Childhood Education

Two recent studies support the conclusion that well-designed computer-based activities, when presented with the active participation of a professional teacher or trained tutor, can increase young children's cognitive abilities.

Goldmacher and Lawrence[43] compared two groups of Head Start preschoolers; one group received a computer enrichment program (*Computertots*) and the other group engaged in standard Head Start activities. The computer-based activities involved a wide variety of software, a professional teacher, and monthly themes that integrated important skills that are prerequisites for kindergarten attendance. **Students in the computer group demonstrated improvements in all academic skills tested, and**

their growth in memory and visual perception was significantly greater than that of the non-computer group.

Chang and Osguthorpe[44] investigated the achievement effects on kindergartners of reading instruction involving picture-word processing software and help from specially trained older students (fourth- and fifth-graders).

> *The picture-word processor... allows users to write messages on a computer by simply pressing squares of picture-words on an electronic tablet without having to spell words or use extensive hand-eye coordination.*

The computer-using students performed significantly better than students receiving regular classroom instruction on tests of word identification, picture-word identification, and passage comprehension.

Special Needs Students

Several researchers have recently examined the effectiveness of technology-based instruction for students with special needs, including students identified as learning disabled, low achieving, or in need of special education.

Learning disabled students. Five studies provide evidence of the potential of writing software, expert systems, videodisc, and hypermedia as educational tools for use with learning disabled (LD) students.

Zhang[45] compared the effects on LD elementary students of writing instruction incorporating a writing tool designed especially for LD students, writing instruction incorporating a commercially-available word processing package, and writing instruction without computers. Special features of the LD writing tool include synthesized speech, a dictionary of basic vocabulary words, teachers' and students' word lists, digitized photos of students, and the ability to provide immediate teacher feedback. Students using the LD-specific writing tool made "significantly more progress" than students using word processing or no computers "in terms of mechanical errors amd holistic quality" of their writing.

Garzella[46] compared the effectiveness of an expert system for reading diagnosis and prescription (*CAPER*) to traditional methods of diagnosis and prescription. **Elementary-level LD students of teachers who used the expert system significantly outgained students of teachers using traditional methods in word identification skills.**

Woodward and Gersten[47] report that when teachers of LD high school students used a videodisc program to teach fractions, "almost two-thirds of the students reached or exceeded criterion performance."

Xin[48] found that video technology gave learning disabled elementary students a significant advantage in vocabulary development and achievement in reading comprehension compared to students not exposed to video. Video was used to provide meaningful visual contexts when learning new words.

A fifth study compared the effectiveness of two versions of the computer-based *Student Assistant for Learning from Text* (SALT) in helping LD students "compensate for their reading difficulties."[49] The "basic" version provided information elements found in a basic biology textbook (text passages, illustrations, an outline, and comprehension questions) plus a computerized "notebook."

> *The enhanced version added speech synthesis, an on-line glossary, links between questions and text, highlighting of main ideas, and supplementary explanations which summarized important ideas.*

The enhanced version was designed to more fully take advantage of the computer. **Students scored significantly higher on a comprehension test when using the enhanced software version with hypermedia features.**

Low-achieving students. Four studies suggest that low-achieving students can benefit from computer-based training systems, from carefully designed math basic skills drills, and from integrated learning systems (ILSs).

Skinner[50] investigated the effects of a sophisticated computer-based training course on classroom management for undergraduate physical education majors. The course components included the following: (1) "students progressed through [tutorial and practice] material at a self-determined pace"; (2) "a mastery criteria of 70% was set for each unit quiz"; (3) "demonstrations and lectures were presented to extend knowledge mastered via the text and CBI"; (4) "communication between instructors and students was conducted via a computer bulletin board"; and (5) "proctors and tutors were available as needed by students."

Results on unit quizzes and the final exam showed the superiority of the computer-based training to text-based instruction without computer (but with proctors and tutors available as needed). The benefit of the computer-based approach was markedly greater for low-achieving students than for high achievers.

Researchers from the University of California Santa Barbara[51] studied the effects of specially designed software on students in grades 4-6 identified as needing "extended practice of basic math facts on the computer to increase their speed." The software tests for the time it takes each student to find and press a key, and then factors this "response latency" into timed drills. The software also includes diagnostic testing to determine an appropriate starting level for practice. After using the program to practice on single-digit multiplication problems, students took a timed paper-and-pencil test. **Results indicate that elementary age students needing extended math practice achieved automaticity for single-digit problems and for double-digit problems that required no added operations.**

Swan, Guerrero, Mitrani, and Schoener[52] reported the results of New York City's Computer Pilot Program, which was targeted to educationally disadvantaged students across the elementary-through-high school grade span. The results indicate the effectiveness of 13 comprehensive computer-based instruction programs, many of which are ILS-based. Overall ESs were 0.8 for reading and 0.9 for mathematics. In another study, Schmidt[53] found that a distributed ILS resulted in significantly higher achievement gains in reading, math, and language arts for low-achieving students compared to traditional instruction. **Swan et al.[54] cite four features of computer-based instruction that make a difference for educationally disadvantaged students: (1) it is "perceived by students as less threatening than traditional...instruction"; (2) it provides "extensive drill and practice with immediate feedback"; (3) it offers individualized diagnosis of student strengths and weaknesses; and (4) implementation of such instructional systems "provide students with greater academic support."**

Special education. Sartorio[55] compared preschool special educational instruction that incorporated commercially-available language development software to instruction without computers. The software programs could be used with "appropriate adaptive computer devices." **Special education preschoolers in the class that used the software showed significantly greater improvement in language development as measured by a standardized test.**

SOFTWARE DESIGN CHARACTERISTICS AND STUDENT ACHIEVEMENT

Research supports what experienced, computer-using educators observe every day—specific design characteristics of software make a difference. Studies were identified underscoring the importance of the type of software, instructional control (learner control versus program control), type of feedback, the embedding of cognitive strategies, and the inclusion of animated graphics.

Type of Software

Wood[56] explored the effects on mathematics achievement of two different types of software: a tutorial program and a tool program. The subjects were high school students studying algebra. Whereas the students using the tutorial demonstrated higher achievement in computational skills, the students using the tool evidenced higher achievement in their understanding of algebra concepts. The study suggests that the best choice of software type may depend on the instructional goal. Since success in mathematics requires both computational and conceptual skills, students are likely to benefit from both types of software.

Some software is developed and assigned to students with the intent of improving general problem-solving abilities. McClurg[57] found that different genre of problem-solving software have different effects on student abilities. One group of third and fourth graders used software programs that focused on spatial patterning tasks (e.g., detect the pattern, continue a pattern). The other group worked on software challenges involving spatial rotation. The spatial rotation group experienced a significantly greater gain in a test of figural classification than the spatial patterning group. **The author attributes the different gains to the specific conceptual**

skills required to solve the problems presented by each software program. This research suggests the need for educators to closely inspect the challenges provided in problem-solving programs.

Instructional Control

Four recent studies suggest the importance of instructional control (learner control versus program control) as a software design issue.

Dalton[58] explored the effects of an interactive video on comets using two different instructional pacing strategies. One group of fifth and sixth graders worked through a fixed-sequence presentation in which text screens were presented "for a fixed length of time, based on the average reading rate of a group of similar learners." The other group worked through the same fixed-sequence presentation, except that the students controlled the amount of time spent on each text screen. For both groups, follow-up questions were presented untimed. **Students who used the learner-paced version significantly outscored those using the program-paced version on a test of basic facts and definitions.**

Shyu and Brown[59] compared the effects on college students of watching an interactive video under two different learner control conditions. The video demonstrated and explained, step-by-step, how to make an origami crane. One group proceeded in the fixed sequence of steps, with the option to replay the current step as many times as desired but with no opportunity to return to previous steps. The other group had total menu-based control over the sequence of steps, including replay of any step, stopping in the middle of a step, and returning to any previous step; this version of the program also included advisement in the form of a suggested sequence of steps to view. **Students assigned to the total learner control with advisement condition performed significantly better** at folding the paper into a crane.

Lee[60] studied the effects of computer-based instruction on Logo commands using two different strategies for controlling instructional review. Each lesson included a tutorial presentation and follow-up questions. After responding incorrectly to a follow-up question, one group of third graders had the option of reviewing instructional components or continuing on to the next question; students in this group were also regularly encouraged to make a self-assessment of their understanding of the concepts presented. The other group automatically received a review presentation after each wrong answer. **Students in the learner-control review group significantly outperformed the program-controlled review group in measures of metacognitive monitoring.** The learner-control review group needed fewer prompts to identify errors in presented information and fewer prompts to answer questions correctly.

However, research by Kinzie, Sullivan, and Berdel[61] underscores the complexity of the phenomenon of control over instructional review. Two groups of ninth-graders received CAI covering science topics under different control-of-review conditions. One group automatically received appropriate review presentations following practice items and feedback (program control). The other group had the option of choosing less review (learner control). Unlike the experiment reported by Lee, students in the learner-control group were not explicitly directed to make self-assessments of their understanding of the material. Male students using the program-control version significantly outachieved males students using the learner-control version. No significant difference was found for female students.

These last two studies, when considered together, suggest the importance of software that encourages student self-assessment when learner control over instructional review is provided.

Feedback

Recent research suggests that the kind of feedback provided in technology-based instruction can have different effects on learning.

One study compared the effectiveness of answer-until-correct (AUC) feedback and knowledge-of-correct-response (KCR) feedback.[62]

> *...when a student misses a question, the typical AUC feedback is "NO, TRY AGAIN."...KCR feedback provides the learner with the correct answer to a question after one attempt.*

Low-ability students in grade 11 receiving KCR feedback during social studies reading comprehension practice significantly outachieved students receiving AUC feedback. The KCR feedback provided information that students could use to clarify misunderstandings of what they had read, whereas the AUC feedback provided no such information.

Two recent studies explored the impact of advisement as a form of feedback in hypermedia exploration programs. Klayder[63] studied the impact of two levels of "time-and-scope" advisement when using a hypertext program covering more content topics than was the focus of the classroom instruction. Static advisement consisted of a single printed page explaining expectations about content on which to focus. Dynamic advisement added:

> *a constant display of time expectations for the current section [of the program], (2) a continually updated display of the current amount of time spent in the current section, and (3) a display of times remaining in advised sections which appear[ed] when the recommended time for a section had been exceeded.*

Students receiving hypertext with dynamic advisement performed signficantly higher on factual questions on an achievement posttest than did students using hypertext with static advisement. Lee and Lehman[64] investigated the effects of instructional cuing, another form of advisement feedback embedded in a hypermedia exploration program. College students were categorized as having an active, neutral, or passive learning style, based on their performance on a learning styles test. They were randomly assigned to one of two versions of a hypermedia "stack." One version monitored student exploration of screens that elaborated on basic information. If a student tried to advance without accessing the elaborative information, a message would appear advising to probe further; however, the student could choose to ignore the advice. The other version of the program did not provide advice about available elaborative information. Active learners achieved about the same regardless of the hypermedia version used. However, **passive and neutral learners demonstrated significantly higher levels of achievement using the hypermedia version with instructional cuing as feedback.**

Santiago and Okey[65] reported on the effects of two different types of advisement feedback: adaptive advisement and evaluative advisement.

> *Adaptive advisement gives information related to the amount/sequence of instruction the learners need to do based on their initial or current performance level.*

An example of adaptive advisement would be guidance such as "Review the Cell Division Tutorial. Then choose Cell Division Practice on the Main Menu and complete at least three problems."

> *Evaluative advisement [informs students] on current learning level in relation to required mastery level.*

An example of evaluative advisement would be information such as "You answered 6 of 10 questions correctly. You must answer at least 8 of 10 questions correctly to achieve mastery."

The subjects of the study were university students in a pre-service curriculum for prospective teachers. **Students receiving adaptive advisement achieved significantly higher than students receiving evaluative advisement.** The results also indicate that "the effectiveness of adaptive advisement did not depend on the learners' locus of control orientation." Learners with an internal locus of control believe that their circumstances are based on their own behavior. Learners with an external locus of control believe that what happens to them is due to factors outside of their control. (External locus of control is frequently cited as a characteristic of low-achieving students.)

Clariana[66] studied the achievement effects of advisement in the form of progress reports generated by an integrated learning system (ILS). The progress reports showed each activity completed, the percent correct for each activity, the amount of time spent on each activity, and the date the activity was completed. **Students receiving ILS progress reports demonstrated significantly higher mathematics achievement than students who used the ILS without receiving such reports.**

Cognitive Strategies

Three recent studies suggest the learning effectiveness of software with embedded cognitive strategies.

Barba and Merchant[67] explored the effectiveness of science software with embedded cognitive strategies such as repetition and rehearsal of content, paraphrasing, outlining and cognitive mapping, drawing analogies and inferences, specific techniques for reading in the content areas, and using pictorial information. These researchers compared the achievement of 10th grade biology students using two different versions of a *HyperCard* stack on insect classification: one with embedded cognitive strategies and one without. **The students using the version with embedded cognitive strategies significantly outperformed the other students on a subsequent insect classification task. The benefits of embedded cognitive strategies were more pronounced for low verbal learners than for high verbal learners.**

Grossen and Carnine[68] compared the effects on learning disabled high school students of two versions of computer-assisted instruction (CAI) on the logic skills. One version embedded the cognitive strategy of having students generate a diagram as a response to a logic problem before choosing the correct diagram from multiple choices. In the other version, students were presented with multiple choice options immediately, without having to generate a diagram. On a simple transfer task as a measure of achievement, **students receiving the program with the embedded strategy of first generating a response significantly outperformed students who used the plain CAI version. Furthermore, the group that used the version with the embedded strategy significantly outscored the comparison group on the more difficult logic tasks. Students using the embedded strategy version required fewer questions to reach mastery criteria throughout the program without requiring more total instructional time.**

Johnsey, Morrison, and Ross[69] investigated the achievement effects of embedded and detached training in generating elaborations (i.e., illustrative examples) of concepts introduced during computer-based instruction. The students were adult employees taking a computer-based professional development course. Students were divided into four groups, each of which received a different version of the software: major content information only (the control group); major content with experimenter-generated elaborations; preliminary tasks instructing students to generate their own elaborations followed by major content information only (detached training); and major content information followed by an instructional unit on elaboration strategies, their value and features, and specific techniques for applying the strategies (embedded training). Students receiving embedded or detached elaborations training significantly outperformed the control group on recall of information. However, **only the group receiving software with embedded elaborations training showed significantly higher achievement on application of the content to new situations.**

Animated Graphics

Three studies found evidence for the benefits of animated graphics.

Calvert, Watson, Brinkley, and Penny[70] experimented with different versions of a graphic "microworld" designed for young children's language development.

> *...a computer screen depicted a park scene which had a green grassy area, a blue lake, a blue sky, a black train track, and a brown road. Twenty-four...objects... could appear by... typing... the word for the...object.*

In one version, a still-frame object would appear accompanied by a spoken verbal label (using synthesized speech). In another version, an animated object would appear without a spoken label. Poor-reading second graders who used the version with animated objects recalled significantly more words than similar students who used the version with spoken labels. **The animated version "increased the poor readers' verbal recall to the level of their better reading peers."**

Researchers at Texas A & M University studied the effects of animated, computer-based instruction on college students' learning and retrieval in physics.[71] Groups of students were assigned versions of a lesson on Newton's first law of motion that differed according to the level of "visual elaboration" (animated graphics, still-frame graphics, or no graphics). While there was no significant difference in achievement among the groups, students who had interacted with animated graphics required significantly less time to answer post-test questions.

> *[This difference]...indicates that although animation did not affect learning, it helped to decrease the time necessary to retrieve information from long-term memory and then subsequently reconstruct it in short-term memory.*

There are many skills in which it is advantageous to minimize one's information retrieval time (e.g., diagnosis of medical problems or learning deficiencies).

In another study, Rieber[72] examined the effects of animated and still-frame graphics on the intentional and incidental learning of fourth graders. "Intentional learning" refers to the skills and concepts directly taught; "incidental learning" refers to "those objectives that are not directly taught but only implied through contextual cues provided in...[the graphic] displays." Two groups of students worked through different versions of a lesson on Newton's laws of motion developed specifically for elementary grade students. One version included animated graphics and the other version included still-frame graphics. **Using the animated graphics version resulted in significantly higher achievement with respect to both intentional and incidental learning.**

Video

One study found evidence for the advantages of video as an instructional design element.

Researchers at the Learning Technology Center[73] at Vanderbilt University studied the effects of dynamic computer-controlled video on the story comprehension abilities of kindergarten students. They compared a video version of a story to an audio-only version (enhanced to communicate information presented in the video but not mentioned in its accompanying narration). When retelling the story, children who received the video version made significantly more summary and inference statements (representing a meaningful translation of the gist rather than a literal retelling in the story's exact words) and a wider variety of information (e.g., character and setting descriptions; internal states of characters) than children who listened to the audio-only version. The video group was also more likely to include the story's key components (the beginning, the problem, the attempt to resolve the problem, and the final resolution). These results were similar for at-risk and non-at-risk students. The researchers concluded that "video facilitates the formation of mental representations for stories" and suggest that it may help children develop their general sense of story structure, an important pre-reading skill.

The 18 studies focusing on software design characteristics suggest that various types of software, learner control, informative instructional feedback, embedded instructional strategies, animated graphics, and video directly related to the concepts being taught can all contribute to student achievement.

RECENT TECHNOLOGIES AND STUDENT ACHIEVEMENT

Several studies focused on three of the more recent applications of technology to education: telecommunications; videodisc; hypermedia; and adaptive testing.

Telecommunications

In Riel's[74] review of research on the use of networking for collaboration across classrooms in different geographic locations, she found evidence of improved academic skills. Three recent studies further illustrate the merit of using online telecommunications for educational purposes.

Riel[75] described a study by Spaulding and Lake,[76] in which low-achieving remedial writers in New York collaborated on writing projects with students from four other states, France, and Germany via a telecommunications network. According to Riel:

> *The network activity was effective in increasing the writing skills of students who were less socially oriented and less academically skilled, perhaps because of the increased opportunities to interact with and learn from their teachers and peers.*

An evaluation of National Geographic (NGS) Kids Network telecommunications-based science activities[77] found that fourth and fifth graders made significant achievement gains as a result of their involvement. Students in the NGS Kids Network group:

- "...demonstrated significant increases in the use of...graphs for organizing...observations, while [a] control group did not"
- showed significant improvement in data interpretation skills
- demonstrated significant improvement in place knowledge, in the ability to identify map locations using longitude and latitude, in their "understanding of factors contributing to acid rain and [in] their ability to reason about the impact of these factors...."

Smith[78] studied the achievement effects of integrating a computer-based telecommunications network with university courses in education, sociology, geology, and business. Students connected to the network via personal computers to submit assignments, and to interact with the instructor and other students. **Students using the network received significantly higher course grades than equivalent students who did not use the network.**

These studies indicate the benefits of computer-based telecommunications to suppliment the curriculum and to communicate with other learners.

Another form of telecommunications involves real-time video and audio communication via interactive satellite, used to make learning at a distance possible. Martin and Rainey[79] compared the effectiveness of satellite-delivered anatomy and physiology instruction to the same instruction provided face to face. Students from seven high schools received instruction via satellite and students from another seven high schools received instruction in class. The schools were matched according to community population, geographical characteristics, student enrollment, race, gender, and socioeconomic status. Students in both groups were equivalent in science achievement prior to the start of instruction, and all schools involved in the study used the same instructional materials. In all but two of the satellite schools, a local science teacher served as a class facilitator. **Students who received satellite-delivered instruction achieved at a significantly higher level than students experiencing face-to-face instruction.** Contributing factors may have included the local science teachers serving as facilitators and the particular abilities of the distance learning teacher.

Videodiscs

Several recent research efforts found advantages to choosing videodisc as an instructional medium for both pre-college and college students.

Mathematics. Kitz and Thorpe[80] compared the effectiveness of videodisc-based algebra instruction to conventional instruction using a textbook with learning disabled adults preparing for college. **Students using the videodisc significantly outscored the students using the textbook on two different tests of algebra achievement.**

Science. Three studies showed the benefits of videodisc-based instruction in science. McWhirter[81] investigated the achievement effects of a science videodisc on sixth graders studying weather topics. **When the same teachers each taught one group of students using the videodisc and an equivalent group using textbooks, the videodisc group significantly outperformed the textbook group on a test of weather concepts.**

Niedelman[82] compared the effectiveness of an earth science videodisc to textbook-based instruction plus hands-on laboratory experience with 8th graders. The videodisc stressed "core concepts," focused on "causal relationships instead of topics," and used charts as "graphic organizers" to synthesize and organize chunks of interrelated information. **Students using the videodisc achieved at significantly higher levels than students receiving textbook plus hands-on instruction on a test of content knowledge and a test of science problem solving skills.**

Researchers from the University of Oregon[83] explored the effectiveness of videodisc instruction in eliminating common science misconceptions of 8th graders studying earth science. The earth science videodisc was designed to provide "in-depth, conceptually integrated instruction." The researchers referred to misconceptions as *alternative frameworks* (AFs) — common sense ideas and viewpoints about natural phenomena that do not conform to a sound scientific understanding. Of 78 AFs held by students "prior to instruction, only 7 persisted," a statistically significant conceptual change.

> *Only 4% of the high ability [students] showed evidence of possessing AFs on the posttest, compared to 72% on the pretest....Only 6% of the [low ability] students showed evidence of AFs on the posttest, while 88% had AFs on the pretest....On the posttest, the students' responses were nonarbitrary, nonverbatim, and substantive, indicating that meaningful learning... had occurred.*

Social problem solving. Bain, Houghton, Sah, and Carroll[84] compared the effectiveness of three methods for teaching social problem solving to elementary and junior high school students: teacher-led interactive video-based instruction; teacher-led linear video-based instruction; and teacher-led instruction without video support. **Students receiving the video-based instruction achieved at a significantly higher level than students experiencing either of the other approaches.**

Videodisc instruction with college students. Five studies indicate the potential of videodisc-based instruction with college students. A study by Ziegler[85] examined the effectiveness of three different methods of introducing university students to the academic library: interactive video with learner control; linear video; and traditional guided tours. **Students who had used the learner-controlled interactive video scored significantly higher than other students on measures of recall learning and self-perceived effectiveness at using the library.**

Woodruff and Heeler[86] reported on a unique application of interactive videodisc technology—to administer aural tests to university students taking a music appreciation course.

> *[Two]...groups were given study guides that identified aural objectives and specified the location of the musical examples for study.... [One group] was required to take aural tests over each unit in a supervised computer laboratory.... The [other] group did not take the...tests.*

The testing followed a competency-based method developed by Keller[87], which has proved successful in science education.[88] Students who took the aural tests received significantly higher grades on unit exams than the other students.

Johnson[89] compared the effects of three instructional approaches for teaching college-level lessons in human resource development: conventional lecture-demonstration; interactive video with students handling the computer controls; and interactive video with the instructor handling the computer controls. **Both videodisc approaches resulted in significantly higher levels of student achievement than conventional instruction in a test of initial learning and a delayed test to measure retention. There were no significant achievement differences between students who directly controlled the computer and those who did not. This is good news for instructors who wish to use interactive video as a whole class activity.**

Two recent studies provide evidence of the effectiveness of videodisc-based instruction in teacher education. Bitter and Hatfield[90] compared the effects of two methods for teaching about the use of geoboards to elementary education majors, as part of mathematics methods courses. Both approaches began with instructor-led lessons. For one group of students, this was followed by videodisc-based instruction. For the other group, the follow-up consisted of cooperative, hands-on experiences with geoboards and discussion of the application of geoboards to classroom teaching. **While both groups showed achievement gains in knowledge of geoboards as an educational tool, students receiving videodisc-based instruction demonstrated significantly higher gains.** Vitale and Romance[91] examined the effectiveness of videodisc instruction plus supplementary activities focusing on core science concepts with female elementary education majors. One group of students received conventional science methods instruction. The other group followed the same syllabus but also received videodisc-based lessons, completed corresponding workbook activities, and prepared and presented model science lessons. **The students who used the videodisc and participated in the supplementary activities demonstrated significantly higher achievement on a test of application of science concepts.**

These ten studies suggest the effectiveness of interactive videodisc (and other multimedia) technology when the skills and concepts to be learned have a motion-visual or aural component. Note that the videodiscs used in these studies incorporated carefully considered, research-based instructional designs.

One caveat. Research from Indiana University, however, provides an important caveat — the effectiveness of interactive video may depend on students' comfort level with technology.[92] After receiving computer-assisted interactive videodisc instruction, juniors in a baccalaureate nursing program who were more comfortable with the computer significantly outachieved students who were less comfortable. Based on this finding, **the researchers recommended**

> ***...efforts to create an atmosphere for acquiring positive attitudes such as orientation programs, frequent and repeated use, and availability of faculty and support personnel....***

They also found that students with a high need for mobility while learning tended to be less comfortable using interactive video. **The researchers suggested that students with "...high mobility needs should be encouraged to take frequent breaks when using..." computers.**

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CD-ROM

Stine[93] compared the effectiveness of whole language reading instruction with and without interactive CD-ROM, computer-based books with second graders eligible for Chapter 1 remedial programs. **Students who used the CD-ROM books demonstrated significantly greater gains in vocabulary and reading comprehension than students who did not.**

Hypermedia

Reed and Rosenbluth[94] found support for having students become creators of content-based hypermedia. High school seniors at a summer honors academy spent a month learning *HyperCard* and researching the humanities of a period of four decades (including art, history, science, music, literature, and technology). Students were divided into four teams, with each team focusing on a different decade. **Stude·ts who developed hypermedia humanities presentations demonstrated significant increases in their perceptions of how different cultural factors influenced their decade of study and how each factor influenced other factors. Students also showed a significant increase in knowledge of cultural values, historical events, and social reforms.**

Adaptive Testing

Three recent studies indicate the potential of computer-based, adaptive testing in helping students to learn. Adaptive testing presents test items based on the individual student's prior achievement level and/or his or her ongoing performance during testing.

Dalton and Goodrum[95] compared the learning effects of three pre-testing conditions: adaptive testing, traditional full-length testing, and no testing. The adaptive test would stop the student from continuing as soon as it determined that the student would <u>not</u> reach mastery on the test. **The researchers reported significantly higher post-test scores for students who had received adaptive pre-testing.**

A year-long project, Microcomputer Adaptive Testing High-Risk Urban Students (MATH-R-US) resulted in "consistent improvement" of students' math scores after completing weekly adaptive tests.[96]

> *The project was used...by a class in an urban high school with an at-risk predominantly black population and a high rate of absenteeism.*

The tests were designed to accept generative rather than multiple choice responses. The testing software was able to generate practice worksheets tailored to each student's diagnosed weaknesses.

Powell[97] studied the effects of three different methods of computerized testing: selecting items to match students' prior achievement level (i.e., adaptive); selecting items at random; or selecting them based on student choice of difficulty level. **It was found that adaptive testing "required significantly fewer items to reach decisions than did the random-selection tests."** Furthermore, students who measured high in anxiety during testing performed significantly better when taking the adaptive test.

These studies suggest that adaptive testing is more efficient than traditional testing (requiring exposure to fewer items to reach decisions), is highly appropriate for students who suffer from test anxiety, and may result in greater student achievement.

INSTRUCTIONAL DECISIONS AND STUDENT ACHIEVEMENT

Research cited thus far strongly suggests that teacher differences, and differences in the learning environments they establish, impact highly on the effectiveness of educational technology. Several recent studies have highlighted the importance of teacher decisions about student grouping.

Baron and Abrami[98] compared the effects of three grouping strategies when using language arts tutorial software. **They found no significant differences in achievement among upper elementary students working individually, in pairs, or in groups of four.** However, Hooper[99] had different results when exploring the effects of computer-based mathematics instruction using various grouping strategies. One group of fifth- and sixth-graders received training in how to learn cooperatively and then worked in pairs and groups of four at the computer. Another group worked individually on computers. **The students who had worked cooperatively scored significantly higher on a post-test that included factual, application, generalization, and problem-solving questions. This learning advan-**

tage for cooperative groups trained in methods of cooperation was confirmed in subsequent research by Hooper, Temiyarkarn, and Williams[100], who also found that cooperative groups were significantly more efficient learners. The cooperation training students received in the latter two studies may explain the difference in results. Support for this was provided in a study by Repman.[101] She compared the effectiveness of three approaches to collaborative, computer-based instruction with seventh grade social studies students. In one group, students worked without any guidance about collaborative learning process. In another group, students were given a sheet to guide their collaboration (structured condition); they were encouraged to assign roles while working together and to take turns at each role. In the third group, students received the same guidance sheet but also underwent training in collaborative learning before beginning computer-based instruction (training condition). **Students in the structured collaboration and collaboration after training conditions achieved at a significantly higher level than students who collaborated on computer without guidance.**

Researchers from Bar-Ilan University also found advantages to collaboration among sixth-graders studying math using computers in an Israeli school.[102] **Students working in pairs demonstrated higher achievement than students working individually, as measured by both immediate and delayed post-tests.**

In his analysis of existing research on computer-based instruction (CBI) in small groups, Shlechter[103] found no consistent achievement advantage for small group learning. However, he did find that small group CBI was significantly more instructionally efficient. In other words, less instructional time per student was required for small groups than for individuals. A study by Cockayne,[104] involving university students in a biology class, confirms this finding.

Shlechter's analysis also indicated an advantage for lower-ability students working in heterogeneous groups without any disadvantage to higher-ability students. He suggested, however, that heterogeneous grouping may only be best "for students with extreme differences in their abilities."

CONCLUSION

Recent research consistently demonstrates the value of technology in enhancing student achievement. While several researchers have attempted to quantify its achievement effects in isolation, actual use of educational technology does not and should not occur in isolation.

It is the decisions made by well-trained, professional educators that will determine the computer's ultimate instructional effectiveness. The research community has begun to provide information useful in addressing many of these issues.

The research reviewed in this section can inform software developers and publishers as they design software, and can help educators as they attempt to incorporate technology-based learning experiences into the curriculum. Developers and publishers of software can use the findings related to instructional control, feedback, embedded instructional strategies, animated graphics, and video to improve the software programs they produce. And educators can learn how technology helps improve student achievement in a variety of subject areas, and which design characteristics to consider when selecting software. They can also benefit from the research on the positive effects of grouping students for cooperative learning with technology.

Section II: Effects of Technology on Student Self-Concept and Attitude About Learning

Recent research confirms the potential of educational technology to improve students' attitudes about themselves and about learning.

The results of several studies indicate that technology has beneficial effects on student self-concept.[105]

In addition, a review of the literature finds positive effects on attitudes toward language arts, mathematics, science, and social studies.[106]

This section of the report features recent studies of educational technology that address student self-concept and student attitudes toward specific curriculum areas, and reviews research that relates changes in student attitudes to software design characteristics, specific technologies, and specific learner characteristics.

EFFECTS ON STUDENT SELF-CONCEPT

Three recent studies provide evidence of the positive impact of educational technology on student self-concept.

Rhyser[107] examined the effects of integrating computer-based instruction (CBI) in an urban elementary school. Students receiving CBI expressed stronger "feelings of success in school" than students in an equivalent school without CBI. Such feelings are an important component of a positive self-concept.

DeGraw[108] found that fourth graders grew in self-esteem and self-confidence when computers were placed in their homes and their school, as part of the Buddy System Project.

Reglin[109] compared two versions of a college-preparatory seminar on mathematics skills. One group of students received classroom instruction plus computer-assisted instruction (CAI); the other group received classroom instruction only. (Both groups received the same total amount of instructional time.) The classroom instruction-plus-CAI approach resulted in significantly higher gains on a measure of self-concept of academic ability than the classroom instruction-only method. The difference in improvement of self-concept was especially significant for students of low socio-economic status.

Previous research suggests that interaction with educational technology may lead to improved self-concept because: (1) Successful experiences with technology give students a feeling of control over their own learning.[110] (2) Such experiences may increase students' sense of confidence in their abilities to perform in specific learning situations.[111]

All of these studies point to the potential of educational technology to help develop student self-confidence. Students who view themselves as successful are more likely to enjoy school and to put forward their best efforts.

CURRICULUM AREAS AND STUDENT ATTITUDES

Recent research efforts provide support for the effects of technology on positive student attitudes in a variety of curriculum areas.

Language Arts

Five research reports documented improvements in students attitudes when they used technology as part of the language arts curriculum. In their review of computers and basic writing instruction, Valeri-Gold and Deming[112] found that "numerous studies have reported improved student attitudes toward writing while composing on the computer." In a study by Green,[113] inner-city third graders demonstrated significantly greater improvement in attitude toward writing after experiencing a writing process approach with word processing, compared to a similar approach without word processing or a grammar-oriented approach to writing. Owston and others[114] compared eighth graders writing on and off computer. When working on the computer, students wrote significantly longer pieces, and their attitudes toward writing and editing were significantly more positive. Beyer[115] found a similar improvement in attitude toward writing among middle school students who experienced a process approach to writing that included regular word processing.

Anderson-Inman[116] reported on two studies in which keyboarding was found to be a highly motivating method of practicing spelling for low performing students.[117] As a result, students developed "a positive attitude toward spelling practice."

These five studies strongly suggest that integrating computers into the language arts curriculum will help improve student attitudes toward writing and spelling practice.

Mathematics

Three recent studies suggest that technology can have a positive impact on students' attitude toward mathematics.

Webster[118] found that black fifth graders in rural Mississippi who received supplemental CAI evidenced significantly more positive attitudes toward math than similar students who did not receive CAI.

A study by the Cognition and Technology Group at Vanderbilt University[119] assessed improvement in elementary school students' attitudes toward mathematics as a result of experiencing *The Adventures of Jasper Woodbury*, a series of video vignettes designed to stimulate mathematical problem solving. Compared to a group of students who received traditional classroom instruction, the Jasper students

> *...showed [significantly] less anxiety toward mathematics, were more likely to see mathematics as relevant to everyday life, more likely to see it as useful, and more likely to appreciate complex challenges.*

Yusuf[120] compared the effects of Logo-based mathematics instruction to traditional math instruction for students in a predominantly black, urban, middle school. Students receiving the Logo-based instruction demonstrated significantly more positive attitudes toward geometry and toward mathematics in general.

Science

Four recent studies suggest the beneficial effects of technology on student attitudes toward the study of science.

Geban, Askar, and Ilker[121] compared the effects of computer-simulated experiments and two other approaches to laboratory work on high school students' school attitudes toward chemistry. One group of students engaged in computer-simulated experiments in which they were guided through the process of hypothesis development, data collection, data analysis, and drawing conclusions about their original hypotheses. Another group of students participated in conventional laboratory activities. A third group participated in hands-on laboratory activities that stressed hypothesis testing and problem-solving. The computer-simulated method resulted in "significantly more positive attitudes toward chemistry than the other two methods, with the conventional approach being the least effective."

MacArthur and Haynes[122] found that learning disabled students preferred studying science topics using a computer-based *Student Assistant for Learning from Text* (SALT) that included synthesized speech and that took advantage of the computer's hypermedia capabilities (e.g., an on-line glossary, links between questions and text, supplementary explanations). The students favored this "enhanced" version of SALT over a simpler version that more closely resembled a basic biology textbook and "thought that [the enhanced version] helped them learn the material better."

An attitude that science educators typically seek to foster in students is curiosity. Brusic[123] explored the effect of incorporating technology-based science activities on the curiosity of fifth grade students. Students receiving instruction that included technology-based activities measured higher in curiosity than students who received only traditional science instruction ("primarily teacher demonstrations of science experiments").

The TERC Star Schools science and math project[124] has been shown to positively effect student attitudes about tackling unknown questions—one aspect of curiosity. The Star Schools project combined network communication among teachers, innovative curriculum units, specially designed software, and teacher training. Over 900 teachers were involved in the project. A sample of 80 students were interviewed before and after their involvement in the Start Schools curriculum regarding their attitudes about tackling known and unknown questions. Before beginning the Star Schools curriculum, about 80 percent of the students favored known questions, but after the Star Schools treatment, only 64 percent favored such questions. This change in attitude was found to be statistically signficant.

While it is possible to develop interactive science instruction without technology, programs such as computer-simulated experiments, microcomputer-based laboratories, and database software improve students' attitudes toward and increase student curiosity about science.

Social Studies

A study by Yang[125] suggests that a social studies computer simulation of presidential decisionmaking can have a positive effect on student motivation. Eleventh-graders who had experienced the simulation scored significantly higher on a measure of motivation than students receiving traditional, print-based instruction.

This social studies study plus those cited above for language arts, mathematics, and science provide a sense of the wide variety of software types that can positively effect student attitudes. Well-designed tutorial and practice and "enhanced" hyper-textbooks can make challenging concepts and principles easier to understand. For example, students who are visual learners can benefit from still and motion graphics and video presentations included in instructional software. Tool software — software that makes it possible to accomplish a task more easily or effectively (e.g., a word processor or spreadsheet package) — can foster creativity and curiosity and make the task easier to accomplish. For instance, revising an essay on computer means working on just the parts the student wants to change, whereas revising without a computer requires rewriting the entire essay. Simulation software can offer students highly interactive, intrinsically rewarding experiences that textbooks cannot provide. For example, technology can allow students to role-play the president of the United States, an 18th century American pioneer, or an international detective.

SOFTWARE DESIGN CHARACTERISTICS AND STUDENT ATTITUDES

Several studies focused on the issue of learner control in software—the degree to which software lets students determine how they will learn. In addition, one recent study focused on the software design characteristics found to be most motivating by gifted students.

Learner Control. Three studies found support for greater student control over the learning environment. Kinzie, Sullivan, and Berdel[126] compared two groups of ninth graders who received different versions of computer-assisted instruction in science. One group worked on a version in which the program automatically determined when to review instructional material. The other group used a CAI version in which students had control over review materials. The students' decisions about which version to use during a subsequent session indicated significantly higher continuing motivation for the learner-control version.

Shyu and Brown[127] considered the attitudinal effects of an interactive video under two different learner control conditions. The video demonstrated and explained, step-by-step, how to make an origami crane. One group of college students went through the steps in a fixed sequence, with the option to replay the current step as many times as desired before going on to the next step. The other group had total control over instructional sequence but was advised as to the preferred sequence of steps. Students using the version with total learner control plus advisement had significantly more positive attitudes toward instruction and felt more confident.

Tool software typically provides a dramatically greater degree of learner control than does tutorial software. Wood[128] compared the effects of tool and tutorial software on high school students' attitudes toward mathematics. Each software application was integrated with classroom instruction. Students using the tool software scored significantly higher on a measure of positive mathematics attitudes.

In these research efforts, computer programs offering students greater control over their learning environment were found to have beneficial effects on student attitudes.

Designing for Gifted Students. Burt[129] completed survey research on the software design characteristics preferred by gifted elementary school students. Her findings suggest that **gifted students are motivated by computer programs that:**

- **offer students a sense of control over the instructional activity**
- **arouse curiosity**
- **use multiple, appropriate levels of difficulty to provide a sense of challenge**
- **provide feedback that builds the user's self-esteem**
- **include an element of fantasy (i.e., make-believe situations that offer the "potential for taking on roles impossible in actual reality")**
- **have learning activities that incorporate game formats**

Experience suggests that these design characteristics have motivational appeal for students across the ability range.

RECENT TECHNOLOGIES AND STUDENT ATTITUDES

Recent research indicates that computer-based telecommunications, videodisc, CD-ROM, and adaptive testing can positively effect student attitudes. There is also preliminary research suggesting the motivational appeal of virtual reality.

Telecommunications

Spaulding and Lake[130] studied the impact on remedial writers of a telecommunications network project in which they wrote collaboratively with students across the United States and Europe. The researchers found that "students were more motivated to write when the projects were designed by other students than when similar projects were designed by the classroom teacher."

A telecommunications project featuring collaboration between students in New York State and students in Moscow city schools[131] had a positive effect on student interest in international issues and current events. After participating in "student-generated projects such as surveys, polls, articles, newspapers, research, analysis, and creative writing," students involved in the telecommunications project were found to spend significantly more time than non-project students discussing political or social issues, discussing international events, reading news magazines at home, and reading books by foreign authors not assigned by their teachers.

Smith[132] investigated university students' attitudes after completing courses that took advantage of a computer-based telecommunications network. The purpose of the network was to make it easy for students to submit assignments, and to communicate with their instructors and other students. A comparison group of students completed equivalent courses without the benefits of the network. Courses that incorporated the network

> *...received higher overall evaluations and higher instructor ratings than did their traditional course counterparts. Nearly three out of every four students in the [network] group rated the response time, ease in doing assignments, quantity of feedback, quality of the course and their overall experience as better or much better than past courses [without] online computer interaction.*

These two studies indicate that the use of computer-based telecommunications helps to improve students attitudes toward learning. Telecommunications can serve as a motivating focal point of instruction (e.g., as a vehicle for student writing) or can provide a system of student support for traditional instruction.

Videodiscs

Four recent studies suggest the positive impact of interactive videodiscs on student attitudes.

Thorkildsen and Lowry[133] found that elementary students using a videodisc on mathematics core concepts had significantly higher gains in math self-concept than students receiving conventional instructional.

Niedelman[134] compared an earth science videodisc to textbook-based instruction plus hands-on laboratory activities. Junior high students receiving the videodisc instruction were significantly more confident in their science problem-solving skills, more interested in taking science classes, and more positive about their learning experience overall.

Bain, Houghton, Sah, and Carroll[135] found that elementary and junior high school students receiving teacher-led, video-based instruction were significantly more positive about their instruction than students receiving teacher-led lessons without video.

Vitale and Romance[136] found that videodisc instruction plus supplementary activities can have a positive effect on the attitudes of college students preparing to become teachers. One group of students received videodisc-based lessons, completed corresponding workbook activities, and prepared and presented model science lessons. The other group followed the same syllabus but received only conventional science methods instruction. The students who worked with the videodisc and participated in the supplementary activities demonstrated a significantly higher degree of confidence in their knowledge of science concepts.

These studies suggest that videodisc can have an advantage over conventional teaching methods in improving student attitudes toward instruction and toward the subject being taught.

CD-ROM

Newbold[137] compared the effects of CD-ROM and print encylopedias on the attitudes of sixth graders. She found that **students using the CD-ROM encyclopedia were significantly more positive toward writing and toward using the library. After students were given experience with both types of encyclopedias, all students were "more positive toward using electronic encyclopedias as compared to print encyclopedias."**

Adaptive Testing

Dalton and Goodrum[138] found that adaptive pretesting on a computer (that halted testing as soon as "nonmastery was indicated") resulted in higher levels of motivation to continue instruction among fifth and sixth graders than traditional, full-length pre-testing.

Students were more motivated by computer-based, adaptive testing than traditional testing because adaptive testing did not subject them to unnecessarily long periods of failure.

Virtual Reality

Preliminary survey research by Bricken and Byrne[139] suggests the power of virtual reality (VR) to motivate students. Children of middle school age attending a technology summer camp had the opportunity to use, design, and implement virtual reality environments. **When given a choice between a VR experience and other familiar technology-based activities, students almost always preferred VR to using a favorite computer program on screen, to watching television, and to playing video games.**

SPECIAL POPULATIONS AND STUDENT ATTITUDES

Early Childhood Education

Two recent studies suggest that computers can have a positive effect on young children's attitudes toward basic academic skills and on their developing self-concept.

Chang and Osguthorpe[140] found evidence that kindergartners who used a picture-word processor while working with trained older students (fourth- and fifth-graders) improved their attitudes toward reading. Based on a survey, it was found that these young children had significantly better attitudes about reading than an equivalent group of children who had not used computers.

Goldmacher and Lawrence[141] studied two groups of preschool children attending a Head Start program. One group followed the standard Head Start program. The other participated in computer enrichment activities, in addition to standard Head Start activities. The computer-based activities were theme-based and were built around an assortment of software. Students in the computer group exhibited significantly more behaviors indicative of positive self-concept than did students in the non-computer group.

In both of these studies, students using computers in early childhood education programs demonstrated more positive attitudes than children who did not have access to computers.

Special Needs Students

Several researchers have explored the effects of technology-based instruction on the attitudes of students with special needs.

Motivating emotionally disturbed students to remain on task is typically a challenge for special educators. However, Bair[142] found that emotionally disturbed students in grades 6-12 spent more time writing and wrote longer compositions using a word processor than using pencil and paper.

As part of a comprehensive evaluation of computer-based instruction (mostly integrated learning systems) in New York City, Swan and others[143] determined that educationally disadvantaged students were more motivated and less threatened when learning on computers than when learning in regular classroom settings.

Mevarech, Silber, and Fine[144] compared the math anxiety of a group of low-ability sixth-graders working with computers in pairs to an equivalent group working on computers individually. The student pairs showed significantly lower levels of math anxiety than the students working individually.

Wepner[145] reported on the effects of different kinds of reading software on the attitudes of at-risk, inner-city, middle school students. One group of students used drill software that focused on discrete reading skills and testing preparation software. The other group used software that practiced a complex of reading skills in the context of stories built around themes of likely interest to adolescents and young adults. The attitudes of the latter group toward themselves as readers and writers showed significantly greater improvement than the attitudes of the group receiving discrete skills practice.

From these studies, we can generalize that technology can be an effective motivator and can improve the attitudes of special needs students toward learning.

INSTRUCTIONAL DECISIONS AND STUDENT ATTITUDES

Recent research suggests that decisions about how students are grouped when engaged in technology-based instruction can impact on student attitudes.

Researchers from the University of Minnesota[146] found that elementary students using tutorial and drill software in cooperative groups had significantly better attitudes toward their computer lessons than students working independently.

However, Repman[147] found that not all computer-based collaborative learning experiences are alike. Middle school students who received training in collaboration and then engaged in computer-based problem solving demonstrated signficantly higher self-esteem than students who received no collaboration training but solved problems on computer with the aid of printed guidelines on collaboration.

This research suggests that collaboration may enhance the positive effects that technology has on student attitudes and that it is advantageous to begin by training students in the process of collaboration.

CONCLUSION

The research cited in this section provides ample evidence of the power of technology to motivate students and to improve their attitudes about themselves and about learning. These positive effects were found for special needs students and regular education students alike, for students in early childhood education as well as higher education.

Perhaps the most important determinant of student attitudes when using technology is the teacher. Only the teacher can create a friendly, caring environment in which students feel secure and willing to accept the many learning challenges they will face.

However, technology will enhance the environment created by the teacher. Carefully designed software products will afford students ample control over their learning environment, will excite students and hold their interest, and will provide engaging learning experiences that are unavailable in the traditional classroom.

Quality teaching and quality software, together, can improve student self-concepts and student attitudes toward learning.

SECTION III: Effects of Technology on Interactions Involving Teachers and Students in the Learning Environment

Across the United States, educators are addressing the need for restructuring the school learning environment—to make it more student-centered, more interactive, and more of a stimulus for cooperative problem-solving.

Recent research is beginning to shed some light on the positive effects of technology on schools, as a social phenomenon, and on teacher-student and student-student interactions.[148] These interactions were found to make a difference in student academic achievement.[149]

In this section, we report on recent research suggesting characteristics of a desirable technology-based learning environment, explore studies concerning the effects of technology on teacher-student interactions and teachers' instructional behavior, and review research on technology's effects on student interactions.

CHARACTERISTICS OF A DESIRABLE TECHNOLOGY-BASED LEARNING ENVIRONMENT

In her analysis of the effects of computer-based instruction on elementary school achievement, Ryan[150] identified three characteristics of the most effective learning environments: (1) personal interaction among the members of the class (i.e., teacher-student and student-student interaction); (2) "curriculum integration by the teacher"; and (3) inclusion of activities in which students can direct their own learning or express themselves. These characteristics were likely to result in effective learning regardless of grade level.

Ehman, Glenn, Johnson, and White[151] synthesized the results of eight case studies on the use of database software in social studies. They concluded that it is essential that the teacher provide structure when students engage in complex problem-solving using computers. Their recommendations to teachers are applicable to problem-solving with a variety of tool software programs:

- Begin with a unit introduction.
- Provide "clear expectations with a sequence of activities."
- Explain and model essential elements of the problem-solving process, and offer students opportunities to practice these elements.
- Provide for "regular checking of student progress in accomplishing the milestone tasks of problem-solving."

Ehman et al. offer several examples of appropriate structuring by the teacher:

> *Using examples, modeling steps and processes, providing for student practice, debriefing student learning, and sharing outcomes are all essential elements of effective instructional structuring.*

These studies underscore the importance of the teacher's role in creating an effective, technology-based learning environment—an environment that is characterized by careful planning and frequent interaction among students and the teacher.

Given the importance of the teacher's role in computer-based learning, Becker's[152] survey research on the differences between exemplary computer-using teachers and other teachers seems especially important. He found that the best computer-using teachers are more likely to add new curriculum topics to their courses and eliminate or de-emphasize some existing topics as a result of using computers. They also tend to stress more classwork in small groups, to assign software on the basis of group needs, and to include students in the software selection process.

Becker identified personal characteristics that differentiate the best computer-using teachers from other teachers.

> *First, exemplary computer-using teachers spend more than twice as many hours personally working on computers at school as do other computer-using teachers....The second largest difference...is that exemplary teachers have had more formal training in using and teaching with computers.*

According to Becker, the following aspects of the instructional environment increase the likelihood of finding an exemplary computer-using teacher at a school:

- *the existence of a social network of computer-using teachers at the same school*
- *sustained use of computers at the school...to accomplish a goal other than learning: e.g., writing and publishing, or industrial arts or business applications*
- *Organized support for computer-using teachers in the form of staff development activities and a full-time computer coordinator....*
- *Acknowledgement of the resource requirements for effectively using computers—smaller class sizes and funds for software acquisition.*

Becker[153] also identified factors related to developing a school environment in which desirable computer outcomes occur (e.g., many teachers using computers, a variety of staff development activities occurring, more curricular than recreational use of computers, stressing computers as academic tools rather than as a delivery system for basic skills practice). His statistical analysis of survey data suggests that **"substantial district-level involvement in school-level decision-making" and "the active...leadership of a school-level computer coordinator" are key factors.**

These findings suggest the importance of district- and school-level administration in developing a positive environment for educational technology and in improving the quality of computer-using teachers and, thus, computer-based instruction.

EFFECTS OF TECHNOLOGY ON TEACHER-STUDENT INTERACTIONS AND TEACHERS' INSTRUCTIONAL BEHAVIOR

Several studies explored the effects of technology on the interaction patterns of a classroom and on the learning environments that teachers create. In addition, two research efforts focused on the effects of introducing computer networks into the learning environment.

Differences in Classroom Interaction Patterns

Results of a study of Indiana's Model Applications of Technology project[154] indicated that, after using computers for 2 years,"...most of the teachers added cooperative learning techniques to their teaching methods." However, changes in teachers' instructional and management styles depended on teacher attitudes about technology and the hardware configuration at the school.

> *One group treated the computer project as an "extra"...and they used [the computers] to present students with isolated, fragmented activities using selected software...computer use was routine, sometimes boring, [and] remotely related to the curriculum...[This] group was often found in... computer lab sites or sites that had turned [a mobile] mini-lab concept into a [stationary] computer lab.*

The mini-labs were each equipped with eight computers and were intended to rotate from class to class, for purposes of computer-assisted instruction or student multimedia development.

> *...the other group made great strides in finding ways to meaningfully integrate computer use with their curriculum and their daily instruction.... They looked for new ways to teach.... They used more careful planning...this more often occurred in sites where there was a "computer presence" in the classroom and the restraints of [too few computers per student] demanded that the teacher find creative ways to integrate computer use.*

Bradley and Morrison[155] studied the differences between teacher-student interaction patterns in computer labs and in classrooms with less than five computers. They discovered that in classrooms, 70 percent or more of the teachers' time was spent with non-computing students. In computer labs, over 40 percent of the teachers' time was spent academically monitoring or providing explanations to computer-using students, whereas less than 5 percent of the teachers' time was spent on such activities in classrooms. More questioning of computer-using students occurred in labs.

The different findings for classroom-based computer use in these two studies may be explained by different levels of teacher experience and/or different levels of teacher training.

Two studies focused on teachers of learning disabled (LD) students. Woodward and Gersten[156] examined the effects of a videodisc-based fractions program on the subsequent instructional styles of LD high school teachers. After teachers and students completed the videodisc, teaching styles "became more interactive." Garzella[157] investigated the effects of an expert system for reading diagnosis and prescription (CAPER). LD elementary school teachers who used the system reported that it helped guide them in grouping students more effectively.

These four studies, when considered together, suggest that technology can have a beneficial effect on classroom interaction patterns—toward greater interaction among class members and toward more collaborative learning experiences. The research indicates, however, that teacher attitudes and the amount and arrangement of computer hardware are important factors in determining how teachers and students interact.

Technology-Rich Learning Environments

Swan and others[158] evaluated computer-based instruction (primarily integrated learning systems) in New York City and found that learning environments that incorporated computers were

> *...more student-centered and cooperative, that teachers were more the facilitators of learning and that learning was more individualized [than the traditional classroom environment].*

A series of reports by the Apple Classrooms of Tomorrow (ACOT) Advanced Technology Group addressed the changes that teachers underwent as a result of long-term immersion (3 to 5 years) in a technology-rich teaching and learning environment.[159] The technology-rich environment included computers, printers, scanners, videodisc and videotape players, modems, CD-ROM drives, and "hundreds of software titles."

The ACOT researchers have identified five stages of instructional change that occur gradually as a result of radically transforming the technological aspects of the learning environment:

- Entry: Teachers struggled to cope with the changed learning environment.
- Adoption: Teachers moved from the initial struggle to successful use of technology on a basic level (e.g., correlation of drill and practice software to classroom instruction).
- Adaptation: Teachers moved from basic use to discovery of its potential for increased productivity (e.g., use of word processors for student writing).
- Appropriation: Having achieved complete mastery over the technology, teachers used it "effortlessly" as a tool to accomplish a variety of instructional and management goals.
- Invention: Teachers are prepared to develop "entirely new learning environments that utilize technology as a flexible tool." (No teachers observed by the ACOT group has reached this stage yet.)

The researchers found that mirroring teachers' growth and development over time in their uses of technology were positive changes in teachers' beliefs about the instructional enterprise (toward a willingness to experiment), shifts in the roles they and students play (toward more student-centered instruction), and shifts in the relationships among teaching colleagues (toward team teaching).

etworked Learning Environments

Two recent studies indicate the potential of computer-based telecommunications networks in improving teacher-student interaction on college campuses.

According to research by Smith[160], university courses that took advantage of a computer-based network resulted in an increase in "the amount and quality of interaction outside of class"—including teacher-student interaction.

Hartman et al.[161] found that over time, instructors in networked courses substantially increased their use of electronic communication without decreasing their use of standard forms of communication. In comparing networked and non-networked sections of the same course, these researchers observed more teacher interaction with lower-performing students in networked sections and more teacher interaction with higher-performing students in non-networked sections.

Riel[162] reviewed research on the use of networking for collaboration across classrooms in different geographic locations and found evidence of improved social skills and a lessening of ethnic tensions.

Based on their review of network learning research in a variety of educational settings, Riel and Harasim[163] conclude that research should focus on how networks are used for educational purposes. They cite a study by Riel and Levin[164] that yielded several **recommendations for the design of networks:**

> ***Network communities can be created with a group of people with established relationships seeking new ways to coordinate their collective work or with a group...with no prior interactions who share a strong commitment to a specific task.***
>
> ***Easy and reliable access to the network is required for all group members or there needs to be some external motviation for using the system (low cost, job, class requirement).***
>
> ***Groups need some form of leadership. A group needs one or more people who take on the responsibility of monitoring and facilitating group interaction.***

EFFECTS OF TECHNOLOGY ON STUDENT INTERACTIONS

Recent research on educational technology and student interaction has focused on variables such as the learning task, software characteristics, and learner characteristics.

The Learning Task

In his review of research on small group computer-based instruction, Shlechter[165] concluded that the demands of the computer-based learning task may help determine whether student cooperation occurs. As an example, he cites a study in which assigning learners the task of playing

> *...against the computer promoted sharing and helping behaviors while having dyads play against each other fostered competitive behaviors.*

Software Characteristics

Two studies suggest that different software characteristics may have different effects on student interaction patterns.

Nastasi, Clements, and Battista[166] explored the effects of the Logo programming language and of more narrowly focused, problem-solving software on elementary school students' problem-solving ability and their interactions. Logo afforded students far greater control over their learning environment than did the other software included in this study. Students using Logo demonstrated significantly greater growth in problem-solving ability, accompanied by higher frequencies of:

> *cognitive conflict [i.e., conflict about the learning task], attempt at resolution of cognitive conflict... successful resolution of conflict, rule making... [and] seeking approval....*

The researchers suggested that it is Logo's ability to stimulate successful resolution of cognitive conflicts that may explain its superior impact on students' problem solving skills.

Dalton[167] found that a learner-controlled version of an interactive video science lesson resulted in significantly higher rates of interaction among students than a lesson-controlled version.

These two studies suggest that software offering a high degree of learner control may encourage positive interaction among students.

LEARNER CHARACTERISTICS

Two recent studies addressed the effects of computer play on the social interactions of young children. Villarruel[168] found that both special education and regular education preschoolers demonstrated more social discourse when playing on computers than when playing with other age-appropriate toys. Children using problem-solving software evidenced significantly higher proportions of elaboration and word play than children using "discovery-based" software. Rhee and Chavnagri[169] also documented "extensive social interactions" when preschoolers play with computers, most of which is based on the child's own initiation.

Another research effort focused on students with special needs. Hine, Goldman, and Cosden[170] found that learning handicapped students who wrote on the computer in pairs had lower error rates than students working alone. They found evidence for three different explanations of this phenomenon:

> *One member of the dyad [i.e., the less error-prone member] would dominate text entry with a product closely resembling the error-rate characteristics of that individual.*
>
> *...when students were in control of the keyboard and were entering text, they would use their partner as a source of information.*
>
> *...the non-typing member would remain active in the writing process by adopting the role of monitor and offering correction information to the typing member....*

CONCLUSION

The research cited above strongly supports the use of technology as a catalyst for changing the learning environment. Educational technology has been shown to stimulate more interactive teaching, effective grouping of students, and cooperative learning. However, technology as a catalyst is not sufficient by itself. Also essential are teachers who are well-prepared to function in a more open, flexible, student-centered environment. Meaningful change will occur over a period of time. At first, teachers can be expected to struggle with the change brought about by technology. However, they will adopt, adapt, and eventually learn to use technology effortlessly and creatively.

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