13 COMPUTERS IN READING AND WRITING

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Historically, written language and technology have shared a parallel and complementary evolution. The invention of writing was itself an unprecedented technological advancement that led to the emergence of highly technological societies (see Ong, 1982). Successive technological developments such as the invention of the printing press have influenced considerably the nature of written communication. Consequently, technology has frequently played a dominant role in defining what reading and writing skills have been considered important, as well as how and to whom they were taught. A characteristic of the modern era has been an accelerated pace of technological development that has had notable effects on the form, substance, and purpose of written communication.

Computer technology is the latest page in the history of technology and written language. From our present vantage point it is difficult to argue conclusively that the new and unique effects of computer technology on written language will be pervasive and enduring, but there are indications that this may be the case. The use of computers for composing and disseminating textual information electronically is rapidly becoming a common experience. The proliferation of computers in schools, which began in the mid-1970s, when powerful and affordable microcomputers became available, has led to widespread interest in using computers for instruction in the language arts. Paralleling these trends has been the emergence of a prodigious literature concerning the use of computers for reading and writing. In its earliest stages speculative articles and reviews of instructional software dominated this literature (Nancarrow, Ross, & Bridwell, 1984), but gradually it has grown to include empirical studies and theoretical pieces.

Several factors complicate a review of this literature. One is the diversity of applications employing computer technology in reading and writing (cf. Balajthy, 1987; Blanchard, Mason, & Daniel, 1987; Bridwell, Nancarrow, & Ross, 1984; Kamil, 1987; Mason, 1980; Mason, Blanchard, & Daniel, 1983; Nacarrow, Ross, & Bridwell, 1984; Thompson, 1980). Existing research reflects this diversity, but as a result it lacks depth in several areas. It has also suffered from the conceptual and methodological shortcomings that are characteristic of pursuing new areas of inquiry. Another complication is that the rapid advances in computer technology and changes in the patterns of its use make the task of a reviewer akin to reading yesterday's newspapers. Also, despite the current trend towards merging the fields of reading and writing into a broader concern for literacy, there is a lack of symmetry in the way researchers have approached the use of computers in reading and writing.

We have addressed these complications by reviewing the literature that we believe is historically important, significant to our present knowledge base, or useful in

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setting a course for future research. Consistent with the intent of this volume we have approached our task primarily from the standpoint of researchers interested in data and theoretical positions that lead to testable hypotheses. Except when they are clearly pertinent to these goals, we have not reviewed publications that are predominantly speculative, evaluative, or technical. We also decided to omit reading and writing research in which the computer's role is not central to the purpose of the research. This category includes studies that use the computer to record and to analyze data (e.g., recording response latencies and eye movements) or that use a computer as a metaphor to create a model of language processing. We believe that the extent and importance of these applications are self-evident to anyone examining other reviews of reading and writing research such as those in this handbook; in addition, these applications have been discussed elsewhere (e.g., see Kamil, 1987).

Clearly in this review focused on computers, a comparison of reading research to writing research reveals two divergent emphases. Writing researchers have focused primarily on word processing, while reading researchers have explored a more diverse range of applications. Nonetheless, we have employed a single organizational structure to review both lines of research. This structure has two major sections: (1) the use of computers in reading and writing instruction, and (2) comparisons of electronic and conventional texts. A commentary discussing the strengths, weaknesses, and future directions of instructional research is included at the end of the first section. Although much of the research presented in the second section has implications for instruction, this research has been generated primarily by an interest in how reading and writing electronic text may differ from reading and writing conventional text. A discussion of theoretical perspectives that have emerged from this research follows this latter section.

COMPUTERS IN READING AND WRITING INSTRUCTION

Background

Among educators the most visible and widely discussed applications of computers in reading and writing have been related to instruction. Computers have been used to teach and to drill specific reading and writing skills, to keep records in order to manage students' progress, to motivate reluctant readers and writers, and to engage students in a variety of other computer-based activities that have been used to address the goals of language arts instruction (e.g., programming computers, using data bases, and writing with word-processing programs). Computers have also been integrated into teaching activities across the full spectrum of reading and writing instruction, including early literacy skills (e.g., Daiute, 1986; Schaudt, 1987), content area reading (e.g., Blanchard & Mason, 1985), college reading and writing skills (e.g., Alexander, 1984; Hawisher, 1987; Rosenthal, 1987), style analysis and correction (e.g., Kiefer & Smith, 1983); technical communication (Mikelonis & Gervicks, 1985); adult literacy (e.g., Young & Irwin, 1988), and teacher training (e.g., Alvermann, 1987; Vinsonhaler, Weinshank, Wagner, & Polin, 1983, 1987).

Several indicators suggest that computers are currently considered to be an important, ongoing factor in reading and writing instruction. For example, beginning in the mid-1980s, textbooks intended to prepare instructors to teach reading and writing have typically included separate chapters or major sections on the use of computers (e.g., Leu & Kinzer, 1987; Robinson & Good, 1987; Vacca, Vacca, & Gove, 1987). In addition, several books aimed at acquainting teachers with the use of computers in

reading and writing instruction have been published (Balajthy, 1986; Daiute, 1985; Geoffrion & Geoffrion, 1983; Rodrigues & Rodrigues, 1986; Rude, 1986; Schwartz, 1985; Strickland, Feeley, & Wepner, 1987; Wresch, 1984). Major professional organizations like the International Reading Association and the National Council of Teachers of English have standing committees and special interest groups that monitor and disseminate information about the use of computers in reading and writing instruction. The computer in language arts instruction continues to be a topic addressed at professional conferences and in journal articles. Interest in computers for reading and writing instruction is also an international phenomenon. For example, more than 50 projects related to the use of computers for reading and writing have been initiated in Europe (Harrison, 1987; Potter, 1987).

Despite this widespread interest, data gathered since the early 1980s have indicated consistently that computer-based activities are not an integral part of the instructional program in most elementary and secondary schools. A study conducted by the Center for Social Organization in Schools (1983–1984) found that in the typical elementary school one or two teachers used the computer regularly for instruction and that the typical student used a computer for less than a half hour per week. Students in secondary schools used computers more often, but the dominant use was for programming. More recently a report by the Congressional Office of Technology Assessment (1988) estimated that U.S. schools spent approximately $2 billion on computer hardware between 1977 and 1987. In 1987, however, schools averaged only one computer for 30 students. The average student used the computer for one hour per week, a relatively small increase from the early 1980s, given that the number of schools equipped with computers for instructional uses increased from 18 percent to 95 percent between 1981 and 1987.

Other data also suggest that computers are not being used extensively for reading and writing instruction. The study conducted by the Center for Social Organization in Schools (1983–1984), for example, found that fewer than 7 percent of elementary and secondary schools with computers were using them regularly for writing, and that word-processing applications were frequently limited to business education classes. Data from a survey conducted as part of the National Assessment of Educational Progress (Martinez & Mead, 1988) suggest that computers are not being used regularly for instruction across a variety of school subjects. When asked if they had ever used a computer in reading or English classes, only about one-fourth of the third- and seventh-grade students and one-tenth of the eleventh-grade students responded affirmatively.

The use of computers for language arts instruction has also been influenced by the availability and characteristics of commercial software for reading instruction. Information concerning this software can be derived from a number of sources. Survey research conducted by the Technology Assisted Learning Market Information Service (see TALMIS, 1983) revealed that 43 percent of the commercial educational software packages marketed predominantly in the United States were classified by software publishers as designed for language arts instruction. The Educational Products and Information Exchange (EPIE) publishes reviews of educational software and maintains a large data base containing information about language arts software. There were 608 reading programs in this data base in 1984, a 500 percent increase from 1981 (see Haven, 1985, cited in Balajthy, 1987). Rubin (1983) classified the commercial language arts programs in a comprehensive catalog of educational software on the basis of their instructional emphasis. Of the 297 programs classified, only 21 required students to read and comprehend connected text; the remainder focused on individual letters, words, or sentences. Similar findings were reported by Day and Day (1984). They found that of 464 language arts software packages the majority were in the area of vocabulary, spelling, and grammar (51%); programs emphasizing comprehension accounted for only

7 percent of the programs. Reinking, Kling, and Harper (1985) tabulated the characteristics of commercial reading software reviewed in Resources in Computer Education (RICE), a data base containing detailed reviews of educational software. They concluded that typical reading software runs on the Apple II family of computers; employs a drill-and-practice format, often with elements of a game; is targeted for regular instruction in the middle grades; and focuses on reading skills that do not require reading connected texts.

Interpretations of the data from these summaries of commercial software are limited by the rapid changes in computer technology and its use in schools. Furthermore, these summaries omit public domain software as well as computer-based instructional activities that employ software not specifically aimed at language arts instruction (e.g., word-processing and data base programs). Reliable data about how computers are being used for instruction would be useful for characterizing their role in instruction, as would a mechanism for monitoring changes in patterns of their use.

Commercial language arts software has been the object of much criticism, predominantly because of its focus on low-level, isolated skills (see Smith, 1984); its frequent use of drill-and-practice formats (see Chall & Conrad, 1984); and its tendency to evaluate rather than guide students' responses (see Duin, 1987). Although there are a few notable exceptions (e.g., Balajthy, 1984; Siegel & Davis, 1987), much of the support for the use of computers in reading and writing instruction is focused on applications other than the drill and practice of specific skills. There are preliminary indications that publishers of commercial software are beginning to develop more diverse programs for language arts instruction and that they are becoming responsive to the concerns being expressed by educators (Reinking, 1989).

In summary, there is considerable interest in the use of computers for a wide range of applications in reading and writing instruction. This interest has not been linked consistently to commercial software, which although widely available, has been frequently criticized. The results of several national surveys indicate that computers are not being used extensively for instruction in most school subjects, including the language arts. No reliable data are available to indicate precisely how computers are being used for language arts instruction in schools.

Research on the Use of Computers in Reading and Writing Instruction

General Studies of Computer Effectiveness

Despite the lack of comprehensive studies of overall use, substantial research has examined the effects of using computers for particular kinds of instruction across a wide range of topics and age groups. In drawing conclusions about the use of computers for reading and writing instruction, previous reviewers have relied extensively on this research (cf. Balajthy, 1987, 1989; Kamil, 1982, 1987; Tanner, 1984). A general conclusion clearly supported by this research is that computer-based instruction increases student achievement at least as much as more conventional modes of instruction. This conclusion is supported by the results of a series of metanalyses conducted by Kulik (Kulik, Bangert, & Williams, 1983; Kulik, Kulik, & Bangert-Drowns, 1985; Kulik, Kulik, & Cohen, 1980). These analyses found an overall increase in student achievement across studies of computer-assisted instruction (CAI) that employed a variety of dependent measures; the average effect size was .47 and .32 standard deviation units for studies carried out in elementary and secondary schools, respectively. A more recent metanalysis by Roblyer, Castine, and King (1988) examined only studies conducted between 1980 and 1987. In addition, they compared the effectiveness of CAI in

individual curricular areas. Although achievement increased in all the curricular areas studied, reading skills profited least. However, in some curricular areas conclusions were based on a relatively small number of studies.

Another consistent finding is that students have positive attitudes toward using computers and are motivated to use them for instructional activities (Clement, 1981), although extended instruction dispensed by a computer appears to decrease these effects (e.g., Saracho, 1982). Computers have also been found to be cost-effective when compared to other educational interventions. Levin (1986) found that CAI was more cost effective than employing adult tutors, increasing instructional time and reducing class size to 20 students. Of the interventions studied, only peer tutoring was more cost-effective for improving reading achievement (2.2 months of achievement gain for each $100 increase per student, compared to 1.9 months for CAI). Niemiec, Blackwell, and Walberg (1986) argued that Levin's procedures overestimated the effect of peer tutoring and underestimated CAI. Their analysis indicated that the cost-effectiveness of CAI for increasing reading achievement was double that of peer tutoring. Cumulatively, this research suggests that the computer is a viable medium of instruction across various school subjects, including the language arts.

Studies of Computer-Based Reading Curricula

A number of research studies have examined the effects of implementing computer-based reading curricula. To date, no comprehensive computer-based writing curricula have been developed, perhaps because educators considering the use of computers for writing have preferred to use them as an aid for writing as opposed to a management tool for moving students through a well-defined hierarchy of writing skills.

The development of computer-based reading curricula occurred primarily before the widespread availability of microcomputers in the late 1970s. Centrally located mainframe computers dispensed instructional lessons to individual terminals in various locations. The relative difficulty in developing and implementing educational applications dependent on mainframe computers encouraged developers to conceive of projects on a broad scale. Before the widespread availability of affordable microcomputers, it would not have been considered practical or cost effective to develop stand-alone programs aimed at a single reading skill. Thus, between the mid-1960s and the late 1970s, a number of projects, often supported by federal grants, developed around several comprehensive computer-based reading curricula (see Mason, Blanchard, & Daniel, 1983, for an extensive review of these projects).

Work on the first major computer-based reading curriculum was begun in 1964 under the direction of Richard Atkinson at Stanford University and was supported by a grant from the U.S. Office of Education. The result was a comprehensive first-grade reading curriculum, originally designed to eliminate the need for a classroom teacher (Atkinson, 1974). As was common in other early projects, the Stanford approach was to create an "integrated system" in which the computer provided computer-assisted instruction (CAI) and computer-managed instruction (CMI). That is, the computer introduced individual skills, accompanied by appropriate drill and practice (CAI), at the same time it recorded student performance and employed programmed algorithms to make decisions about a student's advancement through a hierarchy of skills (CMI). Atkinson and Hansen (1966) published a report of the Stanford project in the second volume of the *Reading Research Quarterly*. Foreshadowing dominant criticisms of CAI for reading instruction, Spache (1967) argued that the Stanford project ignored the central role of the reading teacher and it overemphasized the mastery of isolated skills in a drill-and-practice format.

Considering the number and scope of these early projects, they produced little research. Mason, Blanchard, and Daniel (1983) annotated 181 references related to more than a dozen major computer-based reading projects developed at various universities. Fewer than five of these citations can be considered published articles that report original research related to reading. The only article from this group that was published in a widely circulated peer-reviewed research journal was an evaluative study of the Stanford materials (Fletcher & Atkinson, 1972). In this study, 50 pairs of first-grade students were matched on the basis of reading readiness scores; one of the students in each pair worked 8 to 10 minutes daily on computer-based reading lessons from the Stanford project, while the other did not. Apparently both students in a pair participated in regular classroom reading instruction, and the control subjects were engaged in unspecified activities, while the experimental subjects worked at the computer. After five and one-half months, experimental subjects outperformed control subjects on a number of reading tests. Significant differences in favor of the experimental subjects included subtests requiring comprehension of connected texts, despite the fact that the Stanford curriculum stressed phonics skills.

More recently there have been fewer attempts to develop comprehensive, computer-based reading curricula, but there are a few notable exceptions. Several private firms have developed comprehensive reading curricula as commercial ventures. Some research, primarily evaluative studies, has focused on these curricula, but in most cases it has been conducted or sponsored by the firms marketing them. For example, several individuals who had directed work on the Stanford project founded the Computer Curriculum Corporation (CCC) and marketed a reading program based on that project. Between 1975 and 1977, CCC conducted a series of evaluative studies involving several thousand third- through sixth-grade students in schools across the United States. Although the summary report outlining the results of these studies (Poulson & Macken, 1978) does not indicate which differences are statistically significant, in general the results supported the earlier study by Fletcher and Atkinson (1972). That is, children who had regular 10-minute periods of computer-based reading instruction in addition to their regular classroom instruction outperformed those who had only classroom instruction.

WICAT Systems is another private firm that has developed integrated systems for computer-based reading instruction. Computer-based activities developed by WICAT range from beginning reading skills in the primary grades to comprehension monitoring strategies in the upper grades. The most extensively researched of WICAT's research and development projects was the Individual Reading and Instruction System (IRIS), supported by a grant from the U.S. Office of Education. Unlike most other integrated systems for reading instruction, the IRIS project focused on developing reading comprehension ability among students in the middle grades. In addition, computer-based activities proceeded from a well-defined theoretical position, namely schema theory. Instead of teaching and drilling specific comprehension skills, students working at a computer read texts and then completed five categories of activities: making inferences, deleting unnecessary sentences, interpreting graphic information, determining logical arguments, and practicing vocabulary. After several months, a formative evaluation of this program in several school systems indicated statistically significant gains in interpretive/critical and content reading as measured by a criterion-referenced test; but after two years there was no evidence of gains on a standardized achievement test (Schnitz, Maynes, & Revel, 1983).

Another commercial computer-based reading curriculum that has been evaluated empirically is the IBM Writing to Read program (Martin, 1984). Although a major component of this program is using the computer to teach children sound-symbol

correspondences, off-line reading and writing are an integral part of the prescribed activities. IBM contracted Educational Testing Service to evaluate the effectiveness of the Writing to Read Program, and a report of findings (Murphy & Appel, 1984) indicated that the program resulted in higher reading achievement among kindergarten but not first-grade students in some schools using the program. Writing samples for students using the program were ranked higher than those for children not using the program. There was no direct evidence, however, concerning the role of the computer-based activities in effecting these increases because students using the Writing to Read program apparently read and wrote more than did students who did not use the program.

A few independent researchers have investigated the effects of commercial computer-based reading curricula. Saracho (1982), for example, investigated the effects of the CCC reading and mathematics curricula on the achievement of Spanish-speaking migrant children in the third through sixth grades. When compared to a control group that received only regular classroom reading instruction, the experimental group that completed the CCC curriculum, in addition to regular classroom instruction, demonstrated greater achievement gains. Norton and Resta (1986) compared the effects of having third- through sixth-grade remedial readers engage in conventional reading activities, problem-solving and simulation software, and one of three commercial computer-based reading curricula. After six weeks, they found statistically significant differences in reading achievement favoring the use of simulation and problem-solving software. However, their decision to group the three commercial programs together as a single treatment that preceded the other treatments precludes generalizing from the results of this experiment.

Most existing computer-based reading curricula have been aimed at children in elementary schools. Computer have also been employed, however, in programs for adults who have inadequate reading skills. For example, applications of computers to enhance literacy in the armed services have been described by Blanchard (1984). Some characteristics of computer-based reading instruction are advantageous for teaching adults. For example, individualized instruction with the aid of a computer can accommodate the flexible schedules of working adults and can also reduce the stigma that may be attached to attending courses that teach beginning reading and writing skills (see Turner, 1988).

Caldwell and Rizza (1979) have reported the results of several evaluative studies designed to determine the effectiveness of a computer-based system of reading instruction for adult nonreaders. The Basic Skills Learning System examined in these studies was developed by Control Data Corporation for the Programmed Logic for Automatic Teaching Operation (PLATO) system (first developed at the University of Illinois; see Obertino, 1974), and was aimed at adults whose reading skills were from the third- to eighth-grade level. Subjects were adults in several learning centers in three states. They found a statistically significant gain in reading achievement for adults using the computer-based program when compared to adults receiving traditional reading instruction. Adults in the Basic Skills groups averaged a gain of 1.12 grade levels in 13 hours of instruction, compared to negligible gains by those receiving traditional instruction for the same period of time. In addition, dropout rates that were as high as 50 percent for the traditional groups were less than 5 percent for the computer groups.

In summary, a consistent finding from investigations of reading curricula is that brief, but regular, computer-based reading lessons can enhance reading achievement. The results of these investigations, however, are based most often on the use of computer-based activities that supplement rather than replace conventional reading instruction. For the most part, the research has also been conducted by private firms

with a commercial interest in the curriculum being investigated. Results have not been published in peer-reviewed journals, and thus this research remains outside the mainstream of academic scholarship. Among those who have developed these curricula, the rationale for using computers is frequently based on the belief that the computer offers a unique capability to match instructional content to the needs of an individual learner.

Research on Specific Instructional Applications

A third category of research includes studies that investigate applications of the computer to specific areas of reading and writing instruction (e.g., improving reading fluency or assisting writers as they develop topics for their writing). In general this research has been conducted more recently; and it has employed stand-alone microcomputers, as opposed to networked terminals serviced by larger, centrally located computers. The rationale that undergirds many of these studies is that a computer is a useful device for extending existing instructional activities. This rationale distinguishes these studies from other studies investigating applications that do not have readily identifiable analogs in existing pedagogical strategies. The latter category includes several studies that have instructional implications but that focus on the unique characteristics of texts displayed electronically and their effect on reading and writing processes. We discuss these studies in a subsequent section of this chapter.

Several studies have examined the use of computer-based activities to develop beginning reading skills. A study by Goodwin, Goodwin, Nansel, and Helm (1986) investigated the effects of using a variety of commercial reading readiness software with preschool children. Subjects were assigned to either an off-line control condition or to one of two on-line conditions that varied as to the type of adult assistance. They found no differences between these groups on a test of reading readiness. Their data, however, were collected during only three 20-minute sessions.

An emerging area of interest in beginning reading instruction is the use of computers equipped with devices that produce synthesized, digitized, or recorded speech. Olson and his colleagues (Olson & Wise, 1987; Olson, Foltz, & Wise, 1986) initiated a series of studies to determine if computer-generated speech feedback can improve decoding skills among disabled readers. The primary purpose of these studies was to compare three types of feedback that can be provided to a reader who identifies an unfamiliar word in text presented on a computer screen: syllable-by-syllable, subsyllable, or whole-word feedback. Preliminary findings indicated that readers' recognition of words pronounced by a synthetic speech device compared favorably with words pronounced by the experimenters (94.5 percent and 98.4 percent respectively). They also found that subjects requested help for approximately 65 percent of the words that they read incorrectly during oral reading. When comparing an on-line speech feedback condition to an on-line condition with no feedback, they found statistically significant differences in favor of the feedback condition for percent of oral errors targeted, postexperimental recognition of targeted and untargeted words, and percent of comprehension questions answered correctly. Although they found some advantage in whole-word feedback, the number of subjects in a pilot study was too small to generate sufficient statistical power.

Roth and Beck (1987) employed digitized speech in two microcomputer programs designed to improve word recognition and rates of decoding. In addition to assessing the effectiveness of the two programs, they employed several dependent measures to investigate how improvements in decoding might affect reading comprehension. In one program, children attempted to construct words when given an initial letter and several alternative endings. Digitized speech provided corrective feedback after errors. The

second program required students to find a letter string that matched a word or "pseudoword" pronounced by the computer. Both activities were embedded in a gamelike format in which subjects accumulated points for accuracy and speed. Their results indicated that after using the programs for 20 weeks (three 20-minute sessions per week), fourth-grade subjects reading below grade level gained in their ability to recognize words and in their comprehension of sentences and propositions, but not of complete passages. However, both the experimental and control groups participated in regular classroom instruction during the experiment and the control group engaged in unspecified activities during the experimental treatment.

Reitsma (1988) compared the effects of three instructional activities designed to increase reading efficiency for beginning readers: oral reading guided by a teacher, reading while listening to a tape-recorded version of a text, and independent reading supported by student-selected pronunciations of unfamiliar words in a text mediated by a computer interfaced with a specially designed tape recorder. Six- and seven-year-old subjects in the three treatments and a control condition read five short stories, each containing 20 difficult target words. Results indicated that guided reading and independent reading with the support of the computer increased reading rate and reduced errors on the target words when compared to the reading-while-listening and control conditions.

An earlier study by McConkie (1983) supports these results. He found that adults who were poor readers made greater gains in reading achievement when they read with computer support that was similar to that used by Reitsma than did adults participating in a program of traditional reading instruction. In a related study Carver and Hoffman (1981) did not employ computer-generated speech but did investigate how a computer-based version of repeated reading (Samuels, 1979) would affect reading achievement. High school students who were poor readers read text displayed on a computer screen. Every fifth word in the text was replaced by a choice between the original word and an inappropriate distractor. Subjects repeatedly read each text until they achieved mastery. Data were gathered over a semester, during which subjects regularly engaged in this activity. They found statistically significant gains in reading fluency and also strong evidence that gains transferred to new materials requiring subjects to engage in the experimental task. Their findings were less robust, however, when subjects progressed to more difficult passages.

Another recent application of the computer to reading instruction is described in an investigation by MacGregor (1988). She developed a "computer-mediated text system" designed to encourage third-grade students to ask questions while reading texts displayed on a computer screen. Questions were either "clarification questions" concerning difficult vocabulary or "focus-of-attention questions" pertaining to literal information in the text. The computer program determined the appropriateness of the question and provided a response. Four treatment groups included two groups that had access to one of the computer-based questioning conditions, a group that had access to both types of questions, and a control group that read passages on the computer screen, but without questions. A comparison of subjects in the three experimental groups to subjects in the control group indicated a significant difference in favor of the experimental groups on measures of vocabulary knowledge and prediction of performance on the vocabulary measure. The performance of subjects having access to both types of questions was not significantly better than the groups having access to only one type of question; nor was there evidence that the experimental treatments had a greater effect on average readers when compared to good readers.

Two studies have compared the effects of off-line and on-line instructional activities in reading. Harper and Ewing (1986) compared junior high school special educa-

tion students' comprehension after reading passages and answering questions either in a workbook or on a computer. Comprehension as measured by percent of questions answered correctly was greater on the computer, but the researchers did not report if the differences were statistically significant; nor did they report information about the relative difficulty of passages and questions in the treatment conditions. Balajthy (1988) had college students complete vocabulary-building activities, using either a worksheet, a computer video game, or a computer drill game. After using each format, subjects rated the effectiveness of the format. Based on their ratings, subjects were divided into high- and low-effectiveness groups that were compared on the basis of achievement, time on task, and interest in the activity. The clearest finding in this study was that performance on worksheets was better and faster regardless of the effectiveness rating, although all subjects rated the worksheets as the least interesting. This study highlights the importance of considering interactions between the medium of instruction, perceived effectiveness, interest, and performance.

When compared to the diverse applications of computers to reading instruction, the interest in using computers for writing instruction has been more narrowly focused. Although a variety of commercial software programs are available for writing instruction, word-processing applications predominate in the research literature. Much of this research has important implications for writing instruction, but it has focused primarily on comparing how writing differs when students write with and without the aid of a computer. Thus, we discuss this research in a subsequent section comparing electronic and conventional text. The research devoted to the use of computers in writing is also narrower in that the subjects tend to be college students or skilled writers (see Schwartz & Bridwell, 1984; Schwartz & Bridwell-Bowles, 1987). At least three factors may account for this characteristic of the writing research: (1) writing is often taught as a separate subject at the college level and subjects who typically have typing skills are readily available; (2) colleges and universities frequently make hardware and software for writing available to students; and (3) many writing researchers are affiliated with college or university departments that teach writing courses; thus they can conduct research in conjunction with their teaching responsibilities.

Despite researchers' emphasis on comparing word processing to conventional writing, a few studies have investigated the effects of using computers for specific applications in writing instruction. Alderman, Appel, and Murray (1978) conducted one of the earliest studies related to computers and writing. They analyzed the effectiveness of PLATO programs that provided drill and practice on mechanical aspects of writing. Although community college students reported positive attitudes toward using the computer programs, there was no evidence that the programs significantly improved their writing.

Burns (1984; Burns & Culp, 1980) developed and investigated a computer program that helped college-level writers develop topics prior to writing about them. The program generated open-ended questions based on heuristic models for developing topics (Aristotelian *topoi* and Burke's pentad) and also provided prompts based on an analysis of students' responses. For example, the program suggested that students wrote more when their responses were short. Subjects reported positive attitudes toward the heuristic models used by the program and toward the use of the computer to assist them in developing topics. They generated more topics for writing and their ideas were more sophisticated than in their invention without computers, but no studies of the actual text they produced were conducted. Gillis (1987) employed a computer program to encourage students in a basic writing course to gather more specific ideas before they wrote. Their responses were compared to students who had human tutors or traditional classroom instruction. The computer-based group outperformed the other

groups on all measures (e.g., focus ratings and holistic ratings of essay quality) except fluency. Even though a pattern in favor of CAI was established, the findings were not statistically significant. No differences between the quantity of ideas generated or used in drafts were found when Strickland (1987) compared CAI that he designed (QUEST and FREE, see McDaniel, 1985) with traditional classroom methods. In addition, he examined a number of ideas generated with the CAI that the students used in their essays and found no significant differences between the CAI group and control groups; only those students who used a freewriting technique without the computer showed significant gains. Several writers have argued that the computer's potential for assisting writers as they develop topics before writing will not be realized until artificial intelligence evolves sufficiently to permit a more open-ended dialogue between the writer and the computer (see Kemp, 1987; Selfe, 1987).

Several studies suggest that positive attitudes towards writing increase when students collaborate with the aid of a computer. Duin, Jorn, and DeBower (in press) had college students use a campuswide computer network to assist in the writing of reports for a technical writing class. An analysis of the electronic messages sent during the writing of reports indicated that students used the network to plan, draft, revise, and format documents. They worked collaboratively, asking for and receiving feedback from other students and from the instructor. Students reported high levels of satisfaction in their use of the computer network for their writing. Eighty-five percent of the students indicated that the computer gave them more time to revise than traditional methods of writing, and 100 percent of them found that the file server, which provided telecommunication with the instructor, was especially helpful in sharing and receiving feedback. Similarly, Bruce and Rubin (1983) and Herrmann (1986) reported that junior high school students wrote more imaginatively and found more ways to improve their writing when they wrote collaboratively with the aid of a computer as opposed to traditional writing activities. Using a computer to communicate with other writers from a distance may also have a positive effect on writing performance, because the students sense the presence of an authentic reader. For example, Levin, Riel, Rowe, and Boruta (1985) found that elementary schoolchildren's writing improved when they used computer networks to communicate with other students.

An area of increasing interest is the use of computers to analyze characteristics of written materials, including instructional applications that provide feedback to writers about their own writing. Much of the development of applications in this area has been conducted at AT&T Bell Laboratories and has resulted in an array of programs collectively referred to as the Writer's Workbench (see Frase, 1987). Feedback in these programs ranges from the identification of mechanical errors and inappropriate constructions to the use of sophisticated algorithms that quantify stylistic features of a text. Although Frase (1987) has reported findings supporting the validity of analyses performed by various Writer's Workbench programs, little research has investigated the effects of using such programs as a means of improving writing. Studies by Kiefer and Smith (1983; Smith & Kiefer, 1982), however, did investigate the effects of using a modified version of Writer's Workbench in college composition courses. They found that although experimental subjects using the computer did not achieve higher holistic scores on their writing, they had positive attitudes toward using the program and scored higher on a postexperimental editing task. Ross and Bridwell (1985) argued that existing programs designed to analyze writing style have been limited to superficial features of writing. They suggested that the lack of adequate linguistic theories and computing power prevent these programs from inferring, interpolating, or connecting ideas at a level that approaches a human reader. Nonetheless, as the power of microcomputers increases, more sophisticated applications may be developed and research will be needed to study the effects of computer-based analyses of text.

Studies investigating specific applications of computers to reading and writing instruction are relatively disjointed, and cumulatively they lack the depth necessary to make generalizations. Preliminary evidence suggests, however, that computers, especially those equipped with devices that produce artificial speech, may provide an effective means for increasing decoding skills and reading fluency. In addition, a consistent finding in studies investigating the effects of computer-based writing activities is that these activities increase positive attitudes toward writing.

Commentary on Instructional Research

Existing research investigating the applications of computers to reading and writing instruction has been criticized for its methodological and conceptual shortcomings. Previous reviewers have detailed these shortcomings for reading (e.g., Balajthy, 1987) and for writing (e.g., Ross & Bridwell, 1985; Hawisher, 1986). The present commentary is limited to a discussion of those conceptual and methodological shortcomings that we believe are more serious and more pervasive. We also suggest ways that researchers might address these shortcomings in future research.

A major methodological limitation affecting existing research is the failure to investigate or to control fully the variables that might explain differences between experimental and control groups. For example, in studies investigating the effectiveness of computer-based instruction, experimental groups have typically completed instructional activities in addition to regular classroom instruction, while comparison groups have been exposed only to classroom instruction. This approach may provide useful information about the "additive" effects of supplementary computer-based instruction, but it does not distinguish the use of computers from other supplementary activities that may be equally effective for increasing achievement. A reasonable explanation for many of the studies that show improvement in reading and writing performance is that the subjects in these experiments have had additional instruction, frequently on those skills tested at the conclusion of the study.

Addressing this limitation leads to several practical problems for researchers who wish to investigate the effectiveness of computer-based reading and writing instruction in elementary and secondary schools. Administrators and teachers may not allow researchers to create treatment groups composed of subjects who are removed from regular classroom instruction for experimental computer-based activities. This issue is especially relevant in the elementary school, where reading instruction is often linked to carefully controlled progress through a basal reading series. In addition, it is difficult to control for effects that may result when subjects not allowed to use a computer during instructional time may feel disappointed. Likewise, the Hawthorne effect may be operating within experimental groups who view the opportunity to use the computer for reading instruction as a welcome novelty, although there is evidence that positive attitudes toward computer-based instruction decrease with increasing exposure to it (e.g., Saracho, 1982; Goodwin et al., 1986). Furthermore, there is evidence that the amount of training on the computer given to subjects prior to the collection of data in reading experiments may affect results (cf. Kunz, Schott, & Hovekamp, 1987; MacGregor, 1988; Reinking, 1988; Reinking & Schreiner, 1985).

Researchers may wish to consider several options for addressing these practical problems. First, selecting subjects that have considerable experience using computers for academic tasks reduces the likelihood that a Hawthorne or novelty effect will be confounded with other variables. Second, using training materials that provide ample time for subjects to become thoroughly familiar with a computer application before data are collected may also be important, although this usually adds considerably to the time and effort required to conduct experiments involving the computer. Finally, when it is

not feasible to remove subjects from conventional instruction, comparison groups need to be selected carefully. One solution, for example, would be to have off-line comparison groups complete supplemental instructional activities related to the dependent measures while experimental groups work on the computer.

A major weakness in existing instructional research involving computers is that many researchers have failed to establish a well-defined conceptual and theoretical base for using computers for reading and writing instruction. Conceptual and theoretical issues play an important role in determining what questions need to be addressed, in making decisions about the design of experiments, and in interpreting results. For example, Clark's (1983) analysis of research comparing instructional media has clearly juxtaposed the fundamental issues that researchers must consider when investigating instructional media. In Clark's view, the selection of a medium for delivering instruction is inconsequential when compared to the selection of instructional content and the method for presenting it. He argues that results indicating advantages for computer-based instruction can be explained by a confounding of media differences with uncontrolled variation in content, method, and novelty effects. Given this premise, the important questions for media researchers to address are related to cost-effectiveness and the affective dimension of using computers for learning. Salomon (1979) has taken an opposing position. In his view, various instructional media have distinct attributes that define their potential to affect cognitive processing. The task of the researcher is to identify potentially important attributes of an instructional medium such as the computer and to study their effects on cognitive processing.

These opposing points of view suggest a common course for future research. In either view, global comparisons of computer-based and conventional instruction are not perceived as being productive except to determine cost-effectiveness. Instead, a profitable direction for future research would be to isolate variables that may account for the increased achievement found in previous studies and to determine which, if any, of these variables are directly related to the technological attributes of the computer. Such research will require researchers to develop underlying theoretical frameworks that include a clear rationale for using the computer for reading and writing instruction. Without a theoretical rationale it will be impossible to make generalizations beyond the conditions of a particular study, even if effects are strong.

These viewpoints also imply that researchers need to investigate a wider range of variables. In addition to achievement, independent and dependent variables might include time on task, motivation, and the social context of implementing computer-based instruction in schools (see McGee, 1987). Given the complex interactions among variables in instructional settings, qualitative studies would be a useful complement to quantitative studies (e.g., see Blackstock & Miller, 1988). Venezky (1983) included a qualitative component when he proposed that the following three types of research be included in attempts to evaluate a computer-based instructional program:

1. A standard pre- and posttest achievement-gains comparison, using standard instruments and control groups.
2. An affective-attitudinal survey of pupils, teachers, and parents, using questionnaires and interviews.
3. A participant-observer anthropological study, using *in situ* observers. (p. 35)

Another weakness in some existing studies is the failure to make a connection between the computer-based instructional activities under investigation and the relevant research and theory related to similar off-line activities. Reading and writing researchers investigating instructional applications of computers need to explain what

benefits may be expected by using a computer to carry out conventional off-line activities and these explanations must be tied to prior research. For instance, Hague and Mason (1986) reported improvements in writing quality when students used computerized readability formulas to determine the average length of sentences and words in their writing. Teachers rated essays higher when they had longer sentences and more polysyllabic words, a finding reminiscent of the sentence-combining research conducted in the 1970s. Students can be taught to lengthen sentences using either method, but previous research suggests that changes are not always rhetorically appropriate (Kleine, 1983), and that, in general, manipulating isolated factors during composing is not likely to produce long-term improvement. In this case, there is little support for using the computer to duplicate an off-line instructional activity that is relatively easy to implement and that research has suggested is of questionable effectiveness.

Establishing Priorities for Instructional Research

As suggested by the latter example, another factor that limits research is the lack of clearly defined priorities for the development of computer-based instructional activities. At issue is the development of a rationale for distinguishing between what *can* be done instructionally with a computer and what *should* be done (Rubin, 1983). The development of such a rationale is framed by responses to basic questions about the nature of reading and writing, how literacy skills are best taught, and what attributes of the computer are most relevant for reading and writing instruction. Wilkinson (1983) has suggested that three criteria be used to set priorities for the development of computer-based instruction in reading and, by implication, in writing. Considering these criteria necessitates an explicit response to basic questions about reading and writing instruction. First, priority should be given to applications that employ the unique characteristics of the computer for displaying text. Second, applications should be based on accepted principles of reading and writing instruction. Finally, higher priority should be given to those applications that address problematic areas of instruction. We believe that instructional research in reading and writing that involves a computer would be improved if researchers would explicitly justify their research in terms of these three criteria.

Several writers have addressed issues related to these criteria. Lesgold (1983), for example, has outlined a specific rationale for using computers in beginning reading instruction. In his view, the computer has two important uses for instruction: providing practice in word recognition and diagnosing children's progress. The computer's advantage in providing practice is its capability to present sometimes tedious practice in game formats that children enjoy. Its advantage in diagnosis is in the prodigious ongoing data that can be used to make on-line instructional decisions. Reinking (1986) has argued that six fundamental advantages of computer-mediated texts should guide its use for reading and writing instruction:

1. Computers can enhance the ability of readers and writers to interact with text.
2. Computers permit the external control of written language processes.
3. Computers can lessen the drudgery associated with some aspects of reading and writing.
4. Computers can provide individualized help and guidance during independent reading and writing activities.
5. Computers can contribute to the development of purposeful communication in school, and thus they can bring together reading and writing activities.
6. Computers can facilitate the gathering of data concerning written texts and the processes of reading and writing.

Other than the many studies of word processing that are discussed in a subsequent section, relatively little research has been conducted on instructional applications of computers to writing; nonetheless, a number of writers have stressed the importance of developing applications that capitalize on the unique attributes of the computer (e.g., Bridwell, Nancarrow, & Ross, 1984) and that reflect current theories and research on writing (Beach & Bridwell, 1984). Miller and Burnett (1987) have also pointed out that the use of computers in the language arts classroom is inevitably affected by the long-standing debate between supporters of holistic as opposed to subskill approaches (Samuels, 1980). Similarly, discussions about priorities for research and development will hinge upon which view predominates.

COMPARISONS OF ELECTRONIC AND CONVENTIONAL TEXTS

Much research has compared electronic and conventional texts. Investigations have ranged from a consideration of inherent differences in displaying text on a cathode ray tube (CRT) to purposeful manipulations of the textual display made possible by computer technology. Underlying this research is the assumption that differences between electronic and conventional texts may affect basic reading and writing processes. Although this notion was initially ill-defined and intuitive, variables of potential significance are beginning to emerge and others are being dismissed as less important. Theoretical positions that relate these variables to current understandings of written language process have also begun to appear. We have grouped the research in this area into two categories: convergent studies that minimize differences between electronic and conventional texts, and divergent studies in which differences are heightened purposefully to improve reading or writing performance.

Convergent Studies

Convergent studies focus primarily on the inherent differences between displaying text either electronically or on printed pages. For example, unlike printed text, text displayed on a CRT is usually created by illuminating configurations of *pixels* (dots of light) against a dark background. A CRT screen may be analogous to a printed page, but it is distinguished by the fact that the visual presentation is more like a window to the contents of a computer's memory (Wilkinson, 1983; Yeaman, 1987). Researchers have been interested in whether these or similar differences affect factors like reading speed, comprehension, and visual fatigue. These studies are convergent in the sense that differences are typically minimized so that results can be attributed to differences inherent in the technologies used to display the text. For example, printed materials may be produced by a dot matrix printer, thus producing identical fonts on the page and on the CRT.

Even though writers must read what they write, minimal differences in textual displays are less relevant to writing; writing researchers have been more interested in word processing, a divergent application that capitalizes on the differences between the computer and conventional writing materials. Thus, this section includes primarily studies related to reading. Another characteristic of the investigations in this category is that many of them have been conducted by researchers in instructional technology, ergonomics, applied psychology, and related fields. The questions addressed and the methods employed in this research are reminiscent of the legibility studies conducted over several decades beginning in the 1930s (see Daniel & Reinking, 1987; Hulme, 1984, for a comparison of legibility factors related to printed and electronic texts).

Although findings are mixed, there is considerable evidence that under some conditions reading speed is slower for texts displayed on a CRT (Gould & Grischkowsky, 1983; Hansen, Doring, & Whitlock, 1978; Kruk & Muter, 1984; Muter, Latremouille, Treurniet, & Beam, 1982). In studies finding statistically significant differences, subjects have often read lengthy texts. For example, Muter and associates (1982) found that subjects reading text from a CRT were 28.5 percent slower than subjects reading the same text from a book, but subjects read continuously for two hours in each condition. Studies using passages of a few hundred words have not found statistically significant differences in reading speed (e.g., Fish & Feldman, 1987; Reinking, 1988).

A series of studies by Haas and Hayes (1985a, 1985b) suggests factors that may account for increased reading times. Consistent with earlier studies, they found that college students required more time to retrieve specific information from texts displayed on sequential computer screens than on printed pages. Differences were not significant, however, when each screen displayed more text or when text-editing functions were added (e.g., the capability to search the text for a particular word). Similarly, Wright and Lickorish (1983) found that proofreading was slower on a CRT, although accuracy was no different when the same text was proofread on printed pages. Based on the results of a subsequent study (Wright & Lickorish, 1984), they concluded that slowness on the CRT was due to the inability of subjects to annotate text on the screen, a clear example of the connection between reading and writing in the learning process.

Despite the frequently observed differences in reading time, there is no evidence that comprehension varies when comparing subjects who read minimally different presentations of printed and electronic texts. Studies finding variations in reading speed have typically not found concomitant variations in comprehension. Fish and Feldman (1987) looked specifically for comprehension differences between subjects reading comparable passages presented either on a computer screen or on printed pages. Controlling for subjects' reading ability, they found no significant differences on measures of comprehension for passages giving directions or providing information. Subjects in most of these studies have been mature readers; but a study by Gambrell, Bradley, and McLaughlin (1987) found no comprehension differences among third- and fifth-grade students reading stories from a basal reading series that were displayed either on printed pages or on the computer screen. One study contradicts these findings. Heppner, Anderson, Farstrup, and Weiderman (1985) found that adults performed more poorly on a standardized reading test when it was presented by a computer. They suggest, however, that poorer performance in the computer condition may have been due to the fact that the test was timed.

Some concern has been expressed about the physiological effects of prolonged reading from CRTs. A review of research by the National Research Council (1983) concluded that there was no cause for concern about radiation emitted by CRTs. There is some evidence that when compared to print, reading from a CRT screen can cause greater visual fatigue (Gunnarsson & Soderberg, 1983; Jelden, 1981; Mourant, Lakshmanan, & Chantadisai, 1981), but this difference may be eliminated as electronic textual displays are improved (Cushman, 1986).

Other studies have examined specific characteristics of electronic texts. These include scrolling versus "windowing" of texts (Bury, Boyle, Evey, & Neal, 1982); optimal screen size (Duchnicky & Kolers, 1983; Yeaman, 1987); computer-generated, fill-justified text (Trollip & Sales, 1986); all-capital versus regular mixed print (Henney, 1983); and automatic phrasing of texts (Jandreau, Muncer, & Bever, 1986). Reading speed has been affected by some of these factors, but there is no evidence that they have a significant effect on comprehension. Several writers (e.g., Merrill, 1985; Rubens & Krull, 1985) have attempted to translate these findings into general guidelines for the

development of textual displays on computer screens. Using conceptual, linguistic, and visual aspects of these guidelines to develop well-designed and poorly designed writing software, Duin (1988) reported that college students performed more capably when using the well-designed software and preferred it over the poorly designed software.

A confounding factor that has been controlled in relatively few studies is subjects' experience in working with computers in general and reading electronic texts in particular. It is reasonable to expect some deterioration in reading performance when subjects who are novice users of a computer read texts presented by a computer. Even readers who have considerable experience in using computers have had considerably more experience in reading conventional printed material. On the other hand, a novelty effect may increase interest in materials presented electronically, and interest is known to affect reading performances (see Wigfield & Asher, 1984). The empirical evidence addressing these issues is conflicting. Heppner, et al. (1985) found that performance was poorer when a standardized test was administered by a computer, whether subjects were nonusers or regular users of computers. Gambrell, Bradley, and McLaughlin (1987) found no difference in comprehension, but elementary school students clearly preferred reading stories on a computer screen. There is some evidence that training and experience may affect results in studies examining the effects of reading electronic texts (cf. Reinking & Schreiner, 1985; Reinking, 1988). Apparently the effect of these factors on reading performance requires further study, and researchers may need to exercise caution in generalizing the results of computer studies that do not control for these factors.

Divergent Studies

In some studies the capabilities of the computer are employed to create electronic texts that are purposefully different from conventional printed texts. Differences are emphasized instead of minimized; therefore, we have categorized them as divergent. The goal of researchers in these studies has been to investigate the possibility that texts presented by a computer might be used to enhance reading and writing in ways that are not possible or feasible with conventional materials. Dependent variables are typically related to comprehension in the case of reading and to a variety of outcomes in the case of writing. Results are frequently discussed in terms of how texts displayed under the control of a computer might uniquely affect basic reading and writing processes.

The clearly dominant focus of writing researchers interested in computers has been on the effects that word-processing applications have on writing. A summary of this research is included in this section because the purpose of word-processing applications is to provide writers with a diverse range of computer-based writing capabilities that are either greatly enhanced by a computer or not feasible without one.

Divergent Studies in Reading

Divergent studies in reading have usually employed computer technology to expand or control readers' options for acquiring information from text. The earliest application to be researched in this category was a form of rapid reading developed by Forster (1970) called *rapid serial visual presentation* (RSVP). In RSVP, text is displayed rapidly one word at a time on a CRT, thus the need for strategic eye movements is eliminated, but so is the readers' control over what can be attended to during reading. Although first employed as a laboratory tool to investigate perceptual processes in reading, RSVP has been studied empirically as an alternative to the rapid reading of printed text. In their review of this research, Just and Carpenter (1987) concluded that in its usual form RSVP

does not have any clear advantage over more conventional rapid reading. They speculate, however, that computer-based "intelligent" control of the presentation based on factors like word frequency and a determination of an individual reader's needs may increase the effectiveness of RSVP.

Another early study in this category investigated the effects of using a computer to adjust a textual presentation to the needs of poor readers. L'Allier (1980) programmed a computer to adjust a text's structure when readers had difficulty comprehending. The adjustment was based on a complex algorithm that took into account factors like reading time, response time for interspersed questions, and performance on comprehension probes. Poor high school readers reading under this condition comprehended texts as well as good readers reading the same texts on printed pages without assistance.

Blohm (1982) provided college students with optimal "computer-aided glosses" to assist them in comprehending two technical passages presented by the computer. Subjects having this option available recalled more idea units from the passages than did subjects reading the passages without glosses on the computer. In a later study (Blohm, 1987), he again had college students read passages presented by the computer, but one group could select among several "lookup aids" that included definitions, analogies, examples, and paraphrases. The number of idea units recalled was again greater for the group having access to assistance provided by the computer. The correlation between the number of lookups requested and the number of idea units recalled was not significant; neither was the difference in reading time between the two groups. Apparently, the subjects in this experiment were efficient in selecting appropriate options to increase recall. However, the design and procedures employed in this study limit generalizations. For example, there was no off-line comparison group and subjects were not permitted to look back to previous portions of the text once they had requested the next textual segment to be displayed on the computer screen.

Reinking and Schreiner (1985) studied the effects of using a computer to help good and poor intermediate-grade readers comprehend six expository passages that were classified as either easy or difficult. The computer was employed to provide definitions of difficult vocabulary, background information relevant to the topic of the passage, the main idea of each paragraph, and a less technical version of the passage. A group reading the passages displayed conventionally on printed pages was compared to three experimental groups reading passages on the computer. Experimental groups included subjects who read the passages with no assistance, with optional assistance, and with mandatory assistance. Findings indicated that comprehension increased for both good and poor readers when they were required to view the assistance provided by the computer and that subjects free to select options preferred the background knowledge option. The interpretation of their results was constrained, however, by an unanticipated interaction between passage difficulty and treatment.

In a related study, Tobias (1987) developed a computer program that required subjects to review relevant portions of text when they answered adjunct questions incorrectly. Subjects in this condition had higher scores on a postexperimental comprehension test than did subjects who could voluntarily review the same material. This finding was limited, however, to comprehension items related to the adjunct questions. In addition, he found no evidence of a relation between subjects' self-report of strategies used to read the passage and their actual use of options provided by the computer. Mandatory review also increased as subjects' anxiety increased. Noteworthy, however, is that text in this study was displayed one sentence at a time.

The cumulative record of research in this area suggests that using a computer to expand or control a reader's options for acquiring information from a text may increase reading comprehension. However, there are only preliminary indications of which

variables may explain these increases. Reinking (1988) replicated his earlier study (Reinking & Schreiner, 1985) to investigate factors that may affect comprehension of computer-mediated texts. As in previous studies, he found increases in comprehension among subjects reading texts displayed by a computer that provided comprehension-related assistance. In addition, he found that when subjects received computer assistance they had significantly greater reading times, but their preference for texts and their estimation of their own learning did not vary significantly when reading texts off-line or in any of the three computer conditions. Original scores were then adjusted to control statistically for differences in reading time. After this adjustment, a strong effect for the treatment remained. Increases in comprehension apparently were not due to increased time on task. He concluded that increased comprehension may be due to deeper and more active processing of the text, which was stimulated by the computer-based assistance.

Other computer applications may be categorized as divergent, but they have not been included in this section for one of two reasons. Either they have not been investigated empirically or research has not addressed specifically how they differ from printed texts. For example, a range of computer applications currently grouped under the rubric *hypertext* have used computers to explore alternative ways of structuring textual information. Information in hypertext is not organized sequentially as in conventional texts, but instead is designed to encourage individual readers to explore flexibly the relations among interrelated textual segments (see Jonassen, 1986; and Weyer, 1982, for detailed explanations of hypertext, several representative applications, and a theoretical rationale for its use). Similarly, computer applications in reading developed by McConkie (1983) and MacGregor (1988) may be classified as divergent, but these applications have been examined primarily from the standpoint of their use for reading instruction. They were discussed, therefore, in a previous section of this review.

Divergent Studies Focusing on Word Processing

There has been much interest in, and some theoretical speculation about, how writing with computers may affect the development of writing ability in young children; but as has been noted in previous reviews (Daiute, 1983, 1985; Woodruff, Bereiter, & Scardamalia, 1981–1982), little empirical research has been conducted to explore these possibilities. One study conducted by Rosegrant (1984) indicated that for some young children writing may be easier with a computer keyboard than with pencils, but there is not enough research to indicate whether there are any substantive advantages for using word-processing activities with young children.

Studies comparing the effects of word processing and conventional writing activities with older school-aged children are mixed. Some studies indicate no significant differences (e.g., Schank, 1986, with fourth-grade students; Duling, 1986, with ninth-grade students), while others favor conventional writing (e.g., Philhower, 1986, with mildly handicapped secondary students). Butler-Nalin (1985), on the other hand, found that junior high school students revised more and reread their papers more often when they composed with a computer. Daiute (1986) reported that junior high school students corrected more errors in their writing with computers, but their revisions were no more extensive than when they composed without it. However, in this study the computer also prompted students to correct their errors.

Most of the research on the effects of word processing has been aimed at college students and accomplished writers, most likely for reasons noted earlier in this chapter (e.g., the availability of subjects with typing skills). Collier (1983) was one of the first to examine the effects of word processing on college-level writers. His case studies

reported mixed results. Students wrote more, revised more, and reported more positive attitudes toward the computer; but difficulties with the word-processing program prevented him from determining whether students' writing improved. Echoing a consistent criticism of subsequent research, Pufahl (1984) faulted Collier's study for not including instruction in composing strategies that might have led students to use the computer more effectively. Using the computer as an enhanced typewriter, rather than a unique tool for composing, is not a valid indicator of how word processing may affect writing processes.

Other researchers have arrived at a similar conclusion. Hawisher (1987) analyzed the writing of advanced college freshmen to determine whether they revised more extensively and more successfully with computers than with their usual methods. After analyzing more than 4,000 revisions on 80 essays, she concluded that the computer alone did not affect the students' writing. Harris (1985) also noted that students revised less frequently and made fewer changes in a text's macrostructure when writing with the computer. These findings are counterintuitive because using a word processor makes revising easier. Harris concluded that unless students are given instruction on how to revise with a computer, they will not make good use of the technological advantages of a word-processing program.

Under similar conditions, however, other researchers have found that composing with the aid of a computer leads to improvements in overall writing quality. Etchison (1986), for example, found that essays written by college freshmen in a composition course were rated higher for overall quality when the students composed them with a word processor. Further analysis indicated that the essays composed at the computer had a greater number of words. Rosenthal (1987) also reported that college students composing with a word processor wrote longer essays with fewer mechanical and grammatical errors.

Bridwell, Sirc, and Brooke (1985) conducted case studies of advanced undergraduates who composed letters and memos in a business writing course. Data included (a) keystroke studies of composing processes (i.e., the computer recorded every key each student pressed while composing), (b) interviews based on "instant replays" of composing episodes using the keystroke data, and (c) analyses of revisions on and off the computer (see Sirc & Bridwell-Bowles, 1988, for a more detailed discussion of these methods). Some students were not as successful with the computer as they were with conventional methods of writing. They claimed that the speed of editing did not allow them to "mull things over." Some did not see the need to continue revising when the computer's printer turned their first effort into a neatly typed draft. For others, the polished look of their writing on the computer screen encouraged them to revise. The researchers concluded that the major effect of composing with the aid of a computer in this study was the increased attention paid to surface detail and the visual appearance of the writing, due perhaps to the emphasis placed on appearance in business writing. Also, the effects of the computer interacted with the students' conception of the task, their success in learning a particular word-processing system, and their writing ability.

Studies focusing on older, accomplished writers complement the findings from studies of college-level writers. Bridwell-Bowles, Johnson, and Brehe (1987) studied the effects of word-processing on Ph.D. candidates employed as professional writers. Subjects' writing strategies were studied both on and off the computer, and they were interviewed about their writing after each writing session over a period of several months. This study revealed unexpected patterns during an early period of adjustment to the computer. The degree of satisfaction with the computer hinged on subjects' existing "rituals" as writers and whether or not they could adapt these to the task of writing with a computer. Subjects characterized as global planners seemed most recep-

tive to the computer during this phase, because the computer allowed them to execute a predesigned plan more easily than conventional methods. Those who wrote to discover what they had to say had more difficulty adjusting; they missed their stacks of paper, charts, and diagrams that helped them formulate their emerging ideas. Analysis of their keystrokes revealed, however, that all subjects steadily gained in speed and facility with the computer so that after several weeks they were as productive as they had been with conventional methods. The researchers argued that it is reasonable to conclude that novice writers, who may not yet have successful writing strategies, should be introduced to specific strategies for composing on computers.

Lutz (1987) asked experienced professional writers to revise their own and others' work on a computer as well as with pen and paper. She analyzed protocols from the writers at work to determine their cognitive strategies for improving writing. She found significant differences between revisions that subjects made on their own compared to others' writing. She concluded that little can be said conclusively about isolated variables such as revising behaviors without taking into account contextual variables like the writer's experience, the task, and the medium—a point that applies to writing without a computer as well.

The existing research on word processing leaves many questions unanswered (Gerrard, 1987), but tentative conclusions are supportable. Despite some promising new research (Bernherdt, Edwards, & Wojahn, 1989), little evidence can be found that word processing alone produces dramatic improvements in writing skill. It is more likely that word processing may contribute to improvements in writing when accompanied by appropriate preparatory and ongoing instructional activities, although there is a paucity of research that directly addresses this possibility or suggests what these activities might be. Under certain as yet ill-defined conditions, the use of computers for writing appears to affect factors like the overall length and quality of written work, the extent to which writers revise, and the attitudes writers have about their work. However, with the exception of the consistent finding that writers have positive attitudes about their writing on a word processor, the strength and direction of these findings have been decidedly mixed. More recent research has suggested that a wider range of variables may need to be considered in order to reconcile these contradictory findings. These factors include word-processing experience, reading ability, preferred writing style, contextual factors like the nature of the writing task, and the characteristics of individual word-processing programs.

The Movement toward Theoretical Frameworks

Theories enable researchers to generate hypotheses that guide experiments and that permit experimental findings to be generalized beyond the conditions of a single study. Much of the existing research that compares electronic and conventional text has not been guided by well-defined theoretical frameworks and thus, taken as whole, it is difficult to interpret. Nonetheless, several rudimentary theoretical positions have emerged recently, and these may be useful for interpreting past research as well as for planning new studies. The movement toward theoretical frameworks is an important development in the study of a phenomenon, and the emergence of theoretical speculation suggests that improvements in the research related to computers may be imminent (see Reinking, 1987). In this section we review theoretical issues related to comparisons of electronic and conventional texts, and we present several evolving theoretical positions.

Wright (1987) has argued that the development of adequate theories may be inhibited until more is known about the optimal formats for displaying electronic and

printed texts. Comparing the performance of subjects reading a text displayed on a high-resolution color monitor to those reading it on a blurred photocopy does not lead to valid generalizations about either medium. Thus, investigating intra- as opposed to intermedia variables is a valid and perhaps more fruitful direction for research. An example of how this approach may prevent misleading generalizations is the comparison of reading speed for electronic and printed texts. The overall research evidence suggests that reading speed may be slower for electronic texts; but when Haas and Hayes (1985b) enhanced the textual display on the computer, reading speed increased to a level that was not significantly different from texts presented on printed pages. Similarly, it is difficult to interpret the results of studies using different word-processing programs when little is known about what characteristics separate good and poor programs.

Several researchers, consistent with their interest in divergent applications of computers to reading, have theorized about the differences between electronic and printed texts. Wilkinson (1983), for example, has argued that the fundamental differences between the computer and the printed page are related to framing, pacing, and control. With the aid of a computer, various units of texts ranging from individual letters to lengthy paragraphs can be presented as a single frame isolated from the remainder of a text. The rate at which these frames are presented to the reader can be controlled and that control can be allocated in varying degrees to either the computer or the reader. Daniel and Reinking (1987) have identified similar factors in a somewhat different framework. They use the label "static legibility" to refer to visual factors that have been associated with the legibility of printed texts and they discuss how these factors apply to electronic texts. They argue that unique factors associated with electronic texts go beyond static legibility to include "dynamic" and "interactive" legibility. *Dynamic legibility* refers to those factors that concern decisions about *when* to display text on a computer screen in addition to *where* it is to be displayed (these factors are similar to Wilkinson's notion of pacing). *Interactive legibility* refers to those factors associated with how a reader interacts with texts displayed via the computer (these factors subsume Wilkinson's notion of control).

Using Salomon's (1979) definition of an instructional medium, Reinking (1987) has argued that computer-mediated text and printed text may be considered separate media. In this view, a medium is defined by how its symbol systems and technological attributes affect cognitive processing. A particular medium requires a learner to employ a unique set of cognitive skills to derive meaning from that medium. Media can also be distinguished by the degree to which their technological attributes permit relevant cognitive skills to be modeled, practiced, or supplanted. He concluded that the technological attributes of computer-mediated text, when compared to printed text, vary considerably along these dimensions and that it may be useful to focus on these differences when developing and investigating computer-mediated text. For example, one way that computer-mediated text may affect cognitive processing during reading is that it can be used to instigate a literal interaction between a reader and a text (as opposed to the figurative interaction that is frequently referred to when discussing the comprehension of printed text).

Hypertext, for example, is an application that clearly illustrates how computers permit texts to respond to the needs of a particular reader. Likewise, the capability of computers to control interactions between a reader and a text (e.g., by limiting a reader's access to text) also illustrates how computer-mediated texts might be used to guide the development of metacognitive awareness and other comprehension skills. Reinking (Reinking & Schreiner, 1985; Reinking, 1988) employed this theoretical rationale to develop a computer-mediated text and to investigate its effect on reading comprehension. He argued that the results of these studies and others in which the

technological attributes of the computer were used to expand or control readers' interactions with the text lend support to this theoretical position. Reader versus computer control has emerged as an important theoretical issue for those interested in studying computer-mediated text (see Reinking, 1986), and the prominence of this issue parallels the interest in learner control among those interested generally in computer-assisted instruction (see Carrier, 1984).

Duchastel (1986) has argued that the differences between text presented in books or by computers revolve around the central problem of how information is accessed. In his view, textual information can be either format structured (e.g., an airline schedule) or semantically structured (e.g., a chapter in a psychology text); and various means for accessing efficiently the information embedded in these structures have evolved over time. Semantically structured information presents a greater challenge for accessing information because it consists of a set of highly interrelated informational elements. A fundamental limitation of books is that they normally require semantically structured information to be presented in a single hierarchical sequence, and thus books do not permit a great degree of flexibility for accessing the information they convey. A computer, however, permits highly flexible and individualized approaches to structuring and to accessing information, but it also limits strategies like browsing to locate information (see Anderson-Inman, 1988). This flexibility implies that the structure of electronic texts may require readers to develop new strategies for locating and processing information. Designers of such texts must also develop methods to prevent readers from becoming disoriented while reading flexibly structured texts (Dede, 1988; Kerr, 1987; Yankelovich, Meyrowitz, & Van Dam, 1985). Like other writers, Duchastel (1986) also highlights the controlled access to information as a defining attribute of electronic texts.

Affective factors associated with instructional media have also been incorporated into theoretical models. Salomon (1984) has proposed such a model and he conducted an experiment to test its validity. Although he compared information presented via printed texts and a television program, the model and the experiment have implications for comparing printed and electronic texts. Simply stated, his model related learning to the amount of mental effort invested, which is mediated by the learner's perception of learning via a particular instructional medium. Subjects in the experiment believed learning from the text was more difficult than learning from television and therefore invested more mental effort while reading, which increased their learning. These results suggest that if readers perceive learning from printed and from electronic texts differently, their perceptions could influence comprehension.

As options for presenting texts electronically increase, theoretical positions must expand to accommodate them. For example, interactive video and other new video-based technologies have made it possible to integrate text, computer-generated graphics, and high-quality audio/video productions into highly flexible formats. Sherwood, Kinzer, Hasselbring, and Bransford (1986) found that using a computer to combine video and text led to greater comprehension. They developed a rationale for their findings, which was based on theories related to contextual learning, the role of environmental mediators, and semantically rich domains for problem solving. Similar theoretical speculation will be required as the display of electronic texts becomes more sophisticated.

The theoretical positions outlined in this section and the research to which they relate also have implications for using computers in reading instruction. For example, the capabilities of the computer to direct more actively a reader's processing of the text might lead to instructional activities designed to develop metacognitive skills.

EMERGING ISSUES AND TRENDS

The computer has been described as a machine that can become a machine (Ellis, 1974). This versatility has spawned increasingly widespread and diverse applications of computers to daily activities, including the ways in which people read and write. Several writers have chronicled the increasing use of computers for reading and writing and they have speculated about the implications of this trend for the future. Halpern and Liggett (1984) described the effects of new technologies like telecommunication, dictation systems, and word processing on writing in the workplace; and they have suggested changes that these technological developments imply for writing pedagogy. A collection of papers edited by Olson (1985) describes how technologies such as videodisc players, CAI in language learning, and mainframe computers affect writers in the humanities. Feldman and Norman (1987) have described how computer-based activities such as publishing, collecting and maintaining data bases, analyzing literature, and developing concordances change the nature of academic writing and how scholarly information is disseminated.

These and similar trends may make moot many of the practical questions addressed by current research. For example, the results of convergent studies comparing minimally different electronic and conventional texts may become more relevant for theory than for practice. Although it is unlikely that printed texts will disappear entirely, the increasingly widespread use of electronic media to compose and to display text is likely to continue. For the future it will be more important to know how to optimize reading performance when texts are displayed electronically. The challenge that this goal presents should not be underestimated. Decades of research devoted to optimizing the display of printed texts have not led to definitive recommendations (see Waller, ch. 14 in this volume). Despite some apparent limitations, the options for displaying texts electronically with the aid of a computer are infinitely greater than for printed texts. Researchers interested in electronic text, therefore, will need to address a more complex array of variables and a broader range of research questions.

The open-ended capabilities of the computer to monitor an individual's performance, to provide individual assistance, and to stimulate active processing of written language suggest that the computer will remain an important tool that significantly expands options for teaching reading and writing. For example, the increasing availability of computerized speech suggests interesting new possibilities for teaching sound-symbol correspondences as well as helping beginning readers decode words during independent reading. Likewise, improvements in computer programs that provide individualized feedback concerning students' writing will allow teachers to focus on more abstract components of the writing process.

Another current trend in instruction is the use of computer technology to develop authentic communicative contexts for reading and writing in schools (Reinking, 1986). For example, computer networks enable students to communicate with a wide variety of individuals beyond the walls of their classroom. This trend contributes significantly to the renewed interest in linking reading and writing activities in schools, and it is supported by the research indicating that writing for conventional school assignments is different from "free writing" outside of school (Kirby & Kirby, 1985). Similarly, due to computers, the often adversarial relationship between teachers and students in school-related writing activities is being replaced by a master-apprentice relationship. The computer has become a means for creating a sequence of temporary drafts that serve as a focus for ongoing student-teacher dialogues about the improvement of written work.

A related development is the increase in *desktop publishing*, the ability to create

materials that are produced with widely available, relatively inexpensive, and easy-to-use microcomputers and printers. This development, coupled with the availability of electronic means for disseminating texts, may affect dramatically the current barriers to disseminating and accessing written information. One indication of this trend is the fact that the *New York Post* reports that half of its profits in 1986 were from selling rights to display the newspaper electronically (Anderson-Inmann, 1988). These developments augur important changes in the publishing industry—changes that will affect reading and writing in ways that are difficult to predict from our present vantage point.

Computers continue to have an expanding role in reading and writing research. In addition to using computers for data analyses, researchers are experimenting with new computer-based procedures to investigate internal cognitive processes. For example, by recording a reader's or a writer's use of a computer to interact with text, a researcher can make inferences about underlying processes (e.g., see Kunz, Schott, & Hovekamp, 1987; Wollen, Cone, Margres & Wollen, 1985). Such methods can corroborate findings derived from traditional methods such as recording physical data (e.g., eye movements) or verbal protocols. Advances in the use of computers to analyze the characteristics of a particular text also provide researchers with a new tool for characterizing and manipulating textual variables. Frase (1987), for example, conducted several experiments investigating writing styles based on computer-generated data concerning verb-adjective ratios and patterns of repetition for syllables and parts of speech.

We began this review by highlighting the historical link between technology and written language. We also suggested that the increasingly widespread use of computers to communicate information may prove to be a significant development in that history. One indication of this trend is that several writers have begun to discuss revising the definitions of literacy to include reading and writing electronically (e.g., Kamil, 1987; Calfee, 1985). The content of reading and writing instruction has begun to reflect these changes, most noticeably in the increasing use of word processors in writing instruction. As electronic texts become more prevalent, educators concerned with the teaching of reading and writing will need to confront these changes. Traditional skills like skimming and scanning printed texts, for example, will need to be reoriented because of the different contingencies associated with locating information from texts displayed by a computer on a CRT screen. The use of the card catalog as a reference source in libraries is quickly becoming obsolete. Students in the future will also need to learn how to search data bases and locate information stored via other electronic means.

These changes are likely to accelerate as new, hybrid forms of computer-mediated text appear. Hypertext, for example, will undoubtedly necessitate the development of new metacognitive strategies for locating and comprehending textual information. Writers of these texts will need new heuristics for approaching writing tasks. To meet the challenges implied by these emerging issues, researchers investigating applications of the computer to reading and writing must be equipped with a knowledge of existing research and an awareness of the critical questions that it defines. So equipped, researchers will be able to provide constructive guidance to our increasing dependence on computer technology for reading and writing.

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