*The effects of computer-mediated text on measures of reading comprehension and reading behavior**

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THIS STUDY investigated a theoretical connection between computer technology and current understandings of reading comprehension. Current models of reading emphasize that reading comprehension is an active cognitive process requiring the reader to interact with text-based information and to monitor comprehension in a quest for meaning. The options for interacting with text displayed on the printed page are limited by conventional print and the reader's internal strategies. Hypothetically, computer technology might influence these processes by manipulating text in ways not available or feasible on printed pages. To explore this possibility, intermediate-grade good and poor readers read short expository passages in four experimental conditions which varied as to the medium of presentation (the printed page or the computer), the availability of computer-mediated textual manipulations, and whether the computer or the reader controlled these manipulations. A three-way analysis of variance on passage comprehension scores revealed main effects for reading ability and treatment as well as a significant Passage Difficulty x Treatment interaction. Results indicated that computer-mediated text can influence reading comprehension and that comprehension was most consistently increased when manipulations of the text were under computer control.

Les effets de textes étudiés par l'intermédiaire d'ordinateurs sur les mesures de compréhension de lecture et d'attitude de lecture

CETTE ÉTUDE a examiné un lien théorique entre la technologie d'ordinateurs et les ententes courantes de compréhension de lecture. Des modèles courants de lecture soulignent le fait que la compréhension de lecture est un procédé cognitif actif qui exige du lecteur qu'il réagisse à partir de l'information tirée du texte et qu'il contrôle la compréhension dans un objectif significatif. Les options concernant l'interaction avec le texte arrangé sur la page imprimée sont limitées par la matière imprimée conventionnelle et les stratégies particulières au lecteur. De manière hypothétique, la technologie des ordinateurs pourrait influencer ces procédés en manipulant le texte de façons non disponible ou realisable sur des pages imprimées. Afin d'explorer cette possibilité, des lecteurs bons et médiocres de cours intermédiaires ont lu de courts passages narratifs selon quatre conditions expérimentales qui variaient d'après le moyen de présentation (page imprimée ou ordinateur), la disponibilité des manipulations textuelles par intermédiaire d'ordinateurs, et selon que l'ordinateur ou le lecteur contrôlait ces manipulations. Une analyse à trois voies des variantes des résultats de compréhension de passages a révélé de principaux effets pour la capacité de lecture et le traitement aussi bien qu'une interaction de traitement de difficulté de passages significative. Les résultats ont indiqué que le texte étudié par l'intermédiaire d'ordinateurs peut influencer la compréhension de lecture et celle-ci augmentait considérablement lorsque les manipulations de texte étaient sous le contrôle d'ordinateurs.

* The dissertation upon which this article is based was among the 10 finalists in IRA's Outstanding Dissertation Award 1983-84 competition. A paper based on the dissertation was presented at the 1985 IRA Annual Convention in New Orleans.

Los efectos de textos intercedidos por computadoras en medidas de comprensión de lectura y de conducta lectora

ESTE ESTUDIO investigó una conección teórica entre tecnología de computadoras y conocimientos actuales en comprensión de lectura. Los modelos de lectura actuales enfatizan que la comprensión de lectura es un proceso cognoscitivo dinámico que requiere que el lector interaccione con la información del texto y ejerza control de su propia comprensión en la búsqueda del significado. Las opciones para interaccionar con un texto presentado en una página impresa están limitados por la imprenta convencional y por las estrategias internas del lector. Hipotéticamente la tecnología de computadoras puede ejercer influencias sobre estos procesos mediante la manipulación de textos en maneras no disponibles o factibles en páginas impresas. Para explorar esta posibilidad lectores de buen y de bajo aprovechamiento en lectura de grados intermedios leyeron pasajes expositivos cortos en cuatro condiciones experimentales que variaron en cuanto al medio de presentación (página impresa o computadora), la disponibilidad de manipulaciones del texto intercedidos por la computadora, y si la computadora o el lector controló estas manipulaciones. Análisis de varianza en tres direcciones en los puntajes de comprensión de los pasajes revelaron efectos principales para habilidad lectora y tratamiento al igual que una interacción significativa entre dificultad del pasaje y el tratamiento. Los resultados indicaron que textos intercedidos por computadoras pueden influenciar la comprensión de lectura y que la comprensión aumentó más consistentemente cuando las manipulaciones del texto estuvieron bajo el control de la computadora.

As an alternative medium for presenting text the computer encompasses a unique set of technological attributes. These attributes may combine in a unique fashion to influence cognitive processing during reading. Although in some ways the presentation of text mediated by a computer is currently more restricted than traditional print (e.g., the amount of text which can be displayed at one time on a computer screen is currently more limited than on the printed page), a number of previously unavailable manipulations are attainable. Employing a computer program to control the presentation of text (computer-mediated text), therefore, may influence reading comprehension. The intent of the present study was to select a set of manipulations which have potential for more actively engaging young readers in processing expository text by externalizing certain variables presumed to influence comprehension.

Text manipulations have included advance organizers (Ausubel, 1963), inserted questions (Rothkopf, 1966), pictures (Samuels, 1970), and adjacent-to-text glosses (Otto, 1980). Research on how these manipulations might increase learning from text has provided mixed results (see reviews by Anderson & Biddle, 1975; Barnes & Clawson, 1975; Hartley & Davies, 1976; Otto, 1980; Schallert, 1980). Apparently the complex interactions among readers, texts, and reading environments decrease the probability of enhancing comprehension via these manipulations (Tierney & Cunningham, 1984). This difficulty is exacerbated when one considers the relatively static nature of text mediated by the printed page. Textual manipulations which have arisen from the technological attributes of the printed page do not permit adaptation to individual readers nor do they insure that readers will choose to use these adjunct aids efficiently in their reading and study (Reinking, 1985). Inserted questions, for example, have been shown to have a deleterious effect on the recall of information not addressed in the questions (Anderson & Biddle, 1975; Hartley & Davies, 1976).

The technological attributes of the computer may permit a more interactive flow of information between the reader and the text. In this study the computer was used to mediate text in an individualized fashion and to monitor and assist an individual reader experiencing comprehension difficulty. It was hypothesized that using the computer to provide such contingencies would facilitate reading comprehension. Further, it was hypothesized that providing op-

tions for intermediate-grade readers to interact overtly with the text would encourage more active processing of the text.

The latter hypothesis is derived from research findings which suggest that younger and poorer readers do not actively monitor or spontaneously apply strategies to enhance their own comprehension (Brown, Campione, & Barclay, 1979; Flavell, Speer, Green, & August, 1981; Garner, 1980; Harris, Kruithof, Terwogt, & Visser, 1981; Markman, 1977; Owings, Peterson, Bransford, Morris, & Stein, 1980; Paris & Meyers, 1981). Although metacognitive strategies are employed less often by younger and poorer readers, these readers do employ the same range of reading strategies as more proficient readers (Olshavsky, 1977). Research also suggests that these readers require minimal prompts to stimulate appropriate metacognitive activity (Bos & Filip, 1982; Wong, 1979). Because it can alter the normal contingencies of independent reading and study, the computer might be used to stimulate more metacognitive activity among these readers and therefore affect comprehension.

Several studies involving high school and adult readers have demonstrated that using the computer to mediate expository text can affect comprehension. Anderson et al. (1974), for example, used a computer to regulate the independent reading of college students in economics classes. Students whose comprehension was monitored by the computer scored significantly higher on final exams than did students who read and studied on their own. L'Allier (1980) used a computer program which automatically lowered the readability estimates of expository text and revised passage structure on the basis of reading time and responses to comprehension probes. The comprehension of low-ability high school readers under this condition was equal to high-ability readers reading text which was not adapted. Using the computer to mediate reader-activated glosses, Blohm (1982) found that college students recalled more idea units than did students reading text on the computer without glosses. McConkie (1983) has reported positive results in using a computer program which provides a pronunciation of unfamiliar words when they are touched on the computer screen. Nonliterate adults using this program were able to read and understand material above their estimated instructional reading level. The present study was conducted to extend these findings to intermediate-grade good and poor readers reading expository text under various conditions of textual mediation.

The technological attributes of the computer permit nearly limitless variations in the textual manipulations which can be brought under the control of a computer program. In selecting how the computer will be used to mediate text, therefore, theoretical guidance is necessary (Wilkinson, 1983). In the present study, criteria consistent with current understandings of the reading process guided the development of the computer programs which mediated the text to the reader. Of primary importance was the selection of computer-mediated textual manipulations which would allow the reader to interact overtly with the text in a search for meaning.

Presumably, the difficulty in externalizing interactions between the learner and text-based information is a factor which makes learning from written text often more difficult than learning from a teacher. Spiro (1980) and Schallert and Kleiman (1979), for example, have argued that teachers can more readily tailor a message to specific needs, activate relevant background knowledge, focus attention on what is important, and monitor comprehension by checking for understanding. Rubin (1980) has also offered a taxonomy of differences between oral and written language which suggests that a reader must ascertain meaning on the basis of fewer tangible referents. The computer was employed in this study to allow intermediate-grade readers to interact overtly with written text in ways which are normally available only during oral communication.

Listeners free to interact with a presenter of expository information may request several categories of information to address comprehension difficulty. Some examples include requests for the definition of key vocabulary, a paraphrase or less technical version of the content, supplemental background information or illus-

trations, and some representation of the content's structure which separates the main ideas and the supporting details.

Each of these requests has a counterpart when considering the comprehension of written text. Each is also a recognized factor in reading comprehension research. For example, the relationship between vocabulary knowledge, comprehension, and text difficulty is well established if not well understood (cf. Anderson & Freebody, 1981; Coleman, 1971). The simplification of text and its effects on comprehension have been studied in relation to traditional readability formulas (Klare, 1984) and more recently in terms of coherence (Beck, McKeown, Omanson, & Pople, 1984). The effects of a reader's background knowledge on comprehension have also been the subject of theoretical speculation and experimental research (Rumelhart, 1981). Finally, the formulation of a gist has been studied in relation to passage structure and the integration of information units into hierarchical representations (Filmore, 1968; Grimes, 1975; Kintsch & van Dijk, 1978; Meyer, 1975).

The computer was used in the present study, therefore, to mediate text relative to these four categories of comprehension factors. Subjects either requested or were provided with (a) definitions of key vocabulary; (b) a simpler, less technical version of the text; (c) supplemental background information; and (d) passage structure in the form of the main idea for each paragraph. The inclusion of these options in the computer-mediated text permitted readers to interact overtly with the text in a manner not easily replicated with conventional print technology (Reinking, 1985).

Using the computer to mediate text also permits the examination of reading and study factors not readily addressed when a reader is confronted with conventional printed materials. First, the control of textual manipulations can reside in the computer program or with the reader. During independent reading of printed pages, the reader is almost entirely in control of what portion of a text is attended to and processed. The effects of using computer-mediated text to regulate a reader's access to the textual display or to the availability of textual manipulations is unknown. The research concerning learner control of instructional content in general is also inconclusive (cf. Carrier, 1984; Steinberg, 1977; Tennyson, 1980). The present study permitted an examination of this control factor during reading and study in that treatments represented a continuum from reader control to program control.

Secondly, allowing a reader to choose specific textual manipulations mediated by a computer permits a recording of that reader's reading and study behavior. One of the vexing problems of metacognitive research has been the difficulty in finding valid and reliable processing measures (Belmont & Butterfield, 1977; Brown, 1980). Introspective or retrospective reports (e.g., Olshavsky, 1978) may not always be valid (Brown, Smiley, & Lawton, 1977) and may also interfere with normal reading processes. Although reliable, measurement of observable behavior during reading and study (e.g., Kavale & Schreiner, 1979; Robinson, 1965) often permits competing explanations of underlying processes. Computer-mediated text permits readers to select manipulations of text which they deem useful in enhancing comprehension. By recording a reader's choices, data can be gathered which are both direct and concurrent to the reader's processing of text. One goal of this study was to explore the feasibility of using computer-mediated text to monitor the reading and study behavior of intermediate-grade readers reading and studying expository text.

In summary, using the computer to mediate text may affect reading comprehension because the technological attributes of the computer enable unique manipulations of text. Comprehension may increase if the computer can be used to relieve the processing burden placed on the reader and/or stimulate more active processing on the part of the reader. Computer-mediated text also permits the regulation of how text is presented to the reader. Finally, recording readers' selections of textual manipulations mediated by the computer may provide a unique measure of reading and study behavior.

Based on the theoretical connection between the technological attributes of the computer and the comprehension of expository text, the following hypotheses guided the present study:

1. The comprehension of intermediate-grade readers reading expository text will be affected by using a computer to mediate manipulations of the text.
2. Comprehension of expository text will be affected by varying control of textual manipulations from the reader to the computer program.

In addition, the following research questions addressed the feasibility of using a computer to gather data on reading and study behavior:

1. Will intermediate-grade readers choose to select computer-mediated textual manipulations to enhance their comprehension?
2. If intermediate-grade readers select textual manipulations mediated by the computer, which category of manipulations will they prefer?

Method

Design

The present investigation was designed to permit comparisons among three treatment groups reading expository text under varying conditions of textual manipulation mediated by a computer. A group reading the same text on printed pages was included to control for unanticipated effects due to reading text with a computer.

The subjects, 104 fifth- and sixth-grade students, were blocked on the basis of reading ability and then assigned randomly to the four experimental conditions. In each condition subjects read six expository passages. Each passage was followed by six comprehension probes. A subject not correctly responding to at least four of the comprehension probes was encouraged to restudy the passage before again attempting to meet this criterion score. Three of the six passages were classified as low difficulty and three were classified as high difficulty on the basis of standard readability formulas. The control and three treatment conditions varied as follows:

1. Subjects read passages off line (on printed pages). No textual manipulations were available (off-line group).
2. Subjects read passages on line (displayed by the computer). No textual manipulations were available (test-only group).
3. Subjects read passages on line and were free to choose from among several textual manipulations which were deemed useful for enhancing comprehension of the passages (select-options group).
4. Subjects read passages on line and then were required by the computer program to view all available manipulations before being allowed to continue (all-options group).

Dependent measures included performance on comprehension probes after each passage, number of trials to criterion, and postexperimental scores on a standardized test of reading comprehension. A three-way analysis of variance (ANOVA) was used to compare means in a 4 (Treatment) x 2 (Reading Ability) x 2 (Passage Difficulty) mixed factorial design where treatment and reading ability were the between-subjects factors and passage difficulty the within-subjects factor. A chi-square was used to test for differences among the categories of manipulations selected by the select-options group.

Subjects

Subjects were drawn from an initial pool of 364 fifth- and sixth-grade students in an urban intermediate-grade school. Only a small percentage of these students had any regular opportunity to use the computers available at the school. Informal interviews with the subjects participating in this study confirmed that only a few had ever interacted with a computer prior to this study.

All students in the initial pool were administered the reading subtests (Vocabulary and Comprehension) of the Stanford Achievement Test, Intermediate Level II (Madden, Gardner, Rudman, Karlsen, & Merwin, 1973). For the purposes of this study, students who achieved a score greater than or equal to the 75th percentile (n = 81) were considered good readers. Students who achieved a score greater than or equal to a 4.0 grade equivalent and less than or equal to the 50th percentile (n = 74) were considered poor readers. Students scoring between the 50th and 75th percentile (n = 130) were not used in order to heighten the contrast between good and poor readers. Students with a score below a 4.0 grade equivalent (n = 79) were not used to reduce the possibility that decoding deficiencies might affect experimental outcomes. Ten good readers and 10 poor readers were randomly selected to pilot the materials and procedures. Fifty-two of the remaining good readers and 52 of the remaining poor readers were then assigned randomly to the four reading conditions.

Materials

Passages. The six experimental passages were adaptations of passages selected from the Science Research Associates (SRA) Reading Laboratory rate builders (Parker, 1963). SRA passages were chosen for the following reasons:

1. The passages were relatively short (140 to 180 words) but could be read in isolation as intact entities.
2. The passages resembled the expository writing typical of elementary school texts.
3. Content of the passages was judged to be unfamiliar to most intermediate-grade students. Prior knowledge of the content was presumed, therefore, to be minimal.
4. Passages had been classified by difficulty.

From the set of passages available in the SRA reading materials, three less difficult and three more difficult passages were selected. Less difficult passages discussed how hail is formed, the rotation of the planet Mercury, and the connection between the need for salt and the first trade routes. More difficult passages discussed the Great Salt Lake, the layers of a piece of film, and the value of pots and pans in early England. A computer program (TIES Readability Utility, Minnesota School Districts Data Processing Joint Board) was used to compute the mean readability of each passage on the basis of seven widely used readability formulas. The mean readability estimates for the less difficult passages were grade equivalent scores of 4.9, 6.2, and 4.7. The more difficult passages had mean estimates of 9.6, 9.0, and 11.2.

A panel of four elementary school reading teachers aided in the selection of the content for the four textual manipulations to be offered by the computer. Each teacher completed a worksheet which asked for the following information about each passage.

1. What 5 to 10 vocabulary words from this passage would you suggest preteaching to intermediate-grade readers to help them better understand the passage?
2. For each paragraph in the passage write a main idea that could be understood by an average intermediate-grade reader.
3. What kind of background information would you teach to help a reader understand this passage?
4. Rewrite the passage so that it could be more easily understood by an average third- or fourth-grade reader.

The computer was programmed to offer the definition of a word used in the original version of the passage if at least three out of four teachers on the panel had selected it. Main ideas, background information, and paraphrases were selected or constructed by the panel as a group after comparing their independently completed worksheets. Split decisions among the four teachers were decided by the experimenter.

Paraphrases of written material may subtly alter the meaning of the original text (Hansell, 1976) or render readability analysis invalid

(Klare, 1984). Special care was taken, therefore, to ensure that the easier paraphrases of each passage did not significantly alter meaning while lowering readability estimates. Teacher panelists were asked to write easier versions, but to preserve the original meaning. No reference to lowering a readability estimate was made. In addition, a group ($n = 16$) of average readers (standardized test scores between the 50th and 75th percentiles) read the revised version of each passage off line and responded to the comprehension probes which had been generated from the original version. A second group ($n = 16$) of average readers read the original versions and also responded to the probes. Unlike subjects in the experimental conditions, these readers were allowed to refer back to the text while responding to the comprehension probes. The means and standard deviations for the number of correct responses to the comprehension probes were computed for each group. The group reading the original versions had a mean of 27.6 and a standard deviation of 3.8. The group reading the revised versions had a mean of 28.3 and a standard deviation of 3.2. A t test for independent data revealed that this difference was not statistically significant, $t(15) = 1.12, p > .05$.

Finally, readability estimates were again computed for each of the revised versions. The mean readability estimates for the revised versions were lower than estimates for the original versions. Grade-level estimates for the low-difficulty revised versions were 4.3, 4.6, and 4.4 respectively. Similarly, the revised versions of the high-difficulty passages had reduced estimates of 4.6, 6.0, and 5.7 (see appendix for a high-difficulty passage and its revised version). These data support the contention that revised versions of the original passages were equivalent in meaning but less difficult to read than the original versions.

Programs and apparatus. A computer program[1] was written for each passage which enabled a reader to select definitions of unfamiliar words, an easier paraphrase of the passage, background information, and the main ideas of each of the paragraphs in the passage. The specific content of these textual manipulations was derived from the work of the teacher panel. Each program enabled the reader to read the original passage, select from among the available textual manipulations, and respond to a set of comprehension probes. In addition, the program recorded the selections made by readers in the course of their reading and study. This program was used to permit subjects in one of the reading conditions (select options) to request help when they experienced comprehension difficulty. The original program for each passage was then adapted to create two alternative versions for the remaining on-line treatments. In one version no textual manipulations were available; readers were branched to the comprehension probes when they had finished reading and studying the passage (test only). The second version required the reader to view all of the textual manipulations at least once prior to attempting the comprehension probes (all options).

Several Apple II plus (48K) microcomputers were employed to run the programs which dispensed on-line treatments. Each computer was interfaced with a standard disk drive and output was displayed on black and white video display monitors. Monitors were placed at eye level a comfortable distance from each subject who sat in front of the computer. Controls such as contrast, brightness, and focus were adjusted by the experimenter to a setting which made reading comfortable. Control knobs were then removed to prevent tampering. All text was double spaced and used a standard upper- and lowercase character set. The maximum amount of text displayed on the screen at one time was eleven 40-character lines which were limited to an area approximately 16 x 16 cm. Subjects used the standard Apple keyboard to interact with the computer-mediated text.

Instruments. Dependent measures included performance on six comprehension probes after each passage and the Comprehension subtest of the Nelson Reading Skills Test, Level B (Hanna, Schell, & Schreiner, 1977) which was administered 1 week after completion of the experiment.

Comprehension probes consisted of six multiple-choice items derived from the content

of each passage and written by the researcher. The 36 items (across six passages) were considered a measure of passage comprehension and were, therefore, constructed to maximize reliability and validity. All items were constructed following a standard format. Each item required knowledge of textually implicit information (Pearson & Johnson, 1972) for a correct response. Correct responses were paraphrases of the text found in the passages in order to test more validly for comprehension as opposed to literal recall of the text (Anderson, 1972). Distractors included information related to but not found in the text, a key word or phrase from the passage which had no relevance to the item, and a response which was false on the basis of information in the passage. (See appendix for sample item.)

Originally 54 items were developed according to these criteria. A sample (n = 33) of average fifth- and sixth-grade readers read the passages and answered all the questions from this item pool. Those items not having a point biserial correlation (responses scored correct or incorrect to total test score) of at least .25 and/or having an item difficulty of .90 or greater were not used. Another sample (n = 30) of average fifth- and sixth-grade readers was selected to test remaining items for passage dependency (Tuinman, 1973). Subjects in this sample were asked to respond as best they could to the items without having read the passages. Any items answered correctly by one third or more of this sample were eliminated or revised. A split-half reliability estimate using the Spearman-Brown formula computed on the remaining 36 items completed by subjects in this experiment yielded a coefficient of .90.

Procedures

After subjects had been assigned to the four experimental groups, each group attended a separate training session led by the experimenter. Subjects were informed that they had been randomly selected to help the experimenter learn more about reading. In each training session subjects were familiarized with the operation of the computer and then completed a sample passage appropriate to their group.

Subjects reported once a week to a work area containing several computers. Each subject was dismissed from his or her regularly scheduled classroom activities to complete two passages at one sitting in each of 3 consecutive weeks. All subjects working on the computers were monitored by the experimenter or a trained assistant. These observers kept students on task, insured that subjects did not observe other treatment conditions, and offered assistance when necessary. Little assistance or intervention was needed. Subjects in the off-line group reported weekly as a group to read two passages under conditions which were comparable to the test-only group. One week after the completion of the experimental treatments, subjects were administered the Comprehension subtest of the Nelson Reading Skills Test (Hanna et al., 1977).

Although intervening conditions varied, all subjects initially read the passages and later responded to the comprehension items under similar conditions. All subjects were directed to read and study each passage until they felt ready to attempt the comprehension items. In each condition subjects were required to respond to six comprehension items after having an opportunity to read and study the passage. In order to continue to the subsequent passage subjects were required to achieve a criterion score of at least four of six correct on the comprehension items. After failing to achieve a criterion score on three attempts, a subject could decide to continue to the next passage or to try again. The number of correct responses out of six was reported to subjects, but they were not informed which items had been answered incorrectly. All subjects read the six passages in a fixed order: two low-difficulty passages, two high-difficulty passages, one low-difficulty passage, and finally one high-difficulty passage.

Treatment groups varied as follows: Subjects in the off-line condition read passages on printed pages until ready to attempt the comprehension items. At that time, the printed passage was returned to the experimenter or an assistant who in turn supplied the subject with six multiple-choice comprehension items. Upon completion of the six items, these were immediately

scored. If four or more of the items were answered correctly, the subject was given the next passage. If fewer than four were correct, the passage was returned to the subject who was encouraged to read and study it again, returning for the comprehension items when ready for another attempt. This procedure was repeated until the subject met the criterion or had attempted the comprehension items three times. At that time, the subject was permitted to continue to the next passage.

Subjects in the test-only treatment were exposed to the same conditions as the off-line subjects except that the text, comprehension items, and reporting of scores were mediated by the computer.

Subjects in the select-options treatment read the original version of each passage which was also mediated by the computer. After having read each passage, however, subjects responded to a question displayed by the computer which asked them to determine if they needed help in understanding the passage. If the response was "no," a subject was routed to the six comprehension items. If the response was "yes," the computer presented a screen which allowed the subject to select one of the four textual manipulations: definition of vocabulary, an easier version of the passage, background information, or the main ideas of the paragraphs in the passage. Subjects were free to select as many of these textual manipulations as they desired. At any time subjects could also request to see the passage again until they decided to attempt the comprehension items. Upon failure to reach the criterion score, subjects were again presented with these options.

Subjects in the all-options treatment read the original version of each passage which was mediated by the computer. They were then required to view all of the available textual manipulations prior to attempting the comprehension items. Each manipulation required a subject to view information presented in a series of computer screens. To ensure that this information could not be quickly bypassed, the computer displayed each screen for several seconds before a subject could request the next screen. After viewing all the available textual manipulations, subjects were permitted to review any of these manipulations and/or to again read the original passage. These options were again available when a subject failed to reach the criterion score.

Results

Passage Comprehension

Subjects in each experimental condition responded to six comprehension items after each of the six experimental passages. A subject's number correct out of six items on his or her first attempt was summed across all six pas-

Table 1 Means and standard deviations for end-of-passage comprehension scores

	Treatment							
	Off line		Test only		Select options		All options	
Text Difficulty	Low	High	Low	High	Low	High	Low	High
Good Readers								
M	13.7	12.1	10.3	11.2	10.6	12.2	13.9	14.8
SD	2.5	3.4	3.8	3.6	3.3	2.7	2.5	2.6
Poor readers								
M	7.7	6.4	5.4	6.8	5.8	7.1	8.3	8.9
SD	2.8	2.3	2.1	2.4	3.0	3.4	3.0	2.8

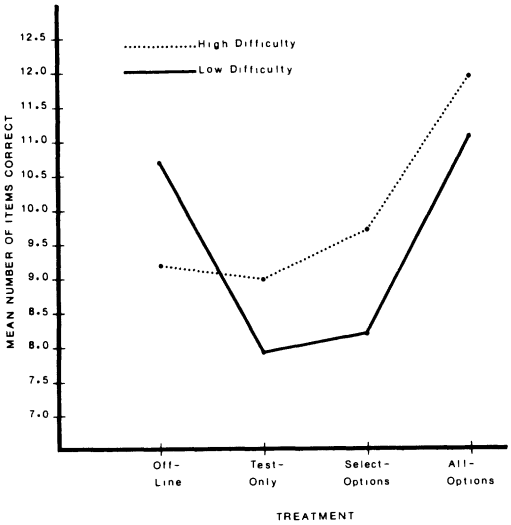
Note. Maximum score = 18. n = 13 for each cell.

sages for a maximum score of 36 (18 for high-difficulty and 18 for low-difficulty passages). Means and standard deviations by experimental condition, reading ability, and passage difficulty are given in Table 1.

A three-way (Treatment x Reading Ability x Passage Difficulty), mixed-factorial ANOVA was employed to test for differences between means for cumulative passage scores. Main effects for reading ability, $F(3, 104) = 126.55$, $p < .001$, and treatment, $F(3, 104) = 8.23$, $p < .001$, were statistically significant, as was the effect for the treatment by passage difficulty interaction, $F(3, 96) = 4.00$, $p < .01$. Unexpectedly, each of the on-line treatment groups scored higher on the more difficult passages while the off-line control group scored lower on more difficult passages, as would be expected. This interaction is presented in Figure 1. Newman-Keuls post hoc comparisons were made between means for experimental groups within difficulty levels. Pairwise comparisons for subjects reading high-difficulty passages indicated statistically significant differences between the all-options group ($M = 11.9$) and the select-options ($M = 9.7$), test-only ($M = 8.9$), and the off-line ($M = 9.1$) groups. Similar comparisons for the low-difficulty passages revealed statistically significant differences between the off-line group ($M = 10.7$) when compared to both the test-only ($M = 7.8$) and select-options ($M = 8.2$) groups. The all-options group's mean score on low-difficulty passages ($M = 11.1$) was also statistically different from the test-only and select-options groups.

Several explanations might account for the unanticipated interaction between treatment and passage difficulty. For example, passages identified as more difficult by readability formulas may have been less difficult due to factors not tapped by these formulas. Although this explanation fails to take into account the performance of the off-line group, it would explain the consistent pattern of the remaining on-line groups. To test this possibility a ratio was computed which compared for each subject in the select-options condition the number of requests for textual manipulations to the number of tests

Figure 1
Treatment by passage difficulty interaction on end-of-passage comprehension scores



taken. A ratio was computed to equalize the effects of those readers who requested many manipulations because they repeatedly failed to meet the criterion score and those readers who requested many manipulations independent of their performance on the comprehension items. A larger value would thus indicate a greater density of requests per passage.

Presumably, if readers were sensitive to differences in passage difficulty, the density of requests for help from the computer would be higher on those passages which had been classified as more difficult. Means and standard deviations for these ratios by reading ability and passage difficulty are given in Table 2. A two-way, mixed-factorial ANOVA performed on these data revealed a significant main effect for passage difficulty, $F(1, 24) = 4.41$, $p < .05$. The observed difference between good and poor readers on request density was not statistically significant, $F(1, 24) < 1.00$. Both good and poor readers free to request textual manipulations, therefore, chose to do so more often on the high-difficulty passages. These data suggest

Table 2 Means and standard deviations for the ratio of options selected to tests taken

Passage Difficulty	Reading Ability: Good Readers	Reading Ability: Poor Readers
Low		
M	1.2	1.1
SD	0.8	0.6
High		
M	1.6	1.3
SD	1.2	0.7

Note. $n = 13$ for each cell.

that subjects reading the passages classified as more difficult found them to be of greater difficulty as indicated by the greater number of requests for assistance in comprehending these passages.

Postexperimental Comprehension

One week after the completion of the last experimental passage all subjects were administered the Comprehension subtest of the Nelson Reading Skills Test. Means and standard deviations by treatment and reading ability are provided in Table 3. A two-way, completely crossed ANOVA computed on this data revealed a significant main effect for ability, $F(1, 96) = 118.70$, $p < .001$, and a significant interaction between treatment and ability, $F(3, 96) = 3.05$, $p < .05$.

Newman-Keuls post hoc comparisons were made between means for experimental groups within ability levels. All pairwise comparisons for good readers were statistically nonsignificant, $p > .05$. The difference between poor readers in the off-line condition ($M = 25.5$) and the select-options condition ($M = 18.5$) was statistically significant. This unexpected finding suggests that the comprehension of poor readers using the computer to select the given textual manipulations may be negatively affected by this condition, at least when compared to readers reading text off line.

Manipulations Selected

To determine the extent to which subjects in the select-options condition selected textual manipulations and which, if any, of the manipulations were preferred, the computer recorded the number of requests for each manipulation. The results were tabulated and are displayed in Table 4. Good readers requested a mean of 2.3 manipulations per passage, and poor readers selected a mean of 3.2 manipulations per passage. Comparing good and poor readers on the ratio of manipulations selected to tests taken (Table 2) reveals, however, that the greater number of selections made by poor readers can be attributed to the greater number of attempts needed to achieve a criterion score. Thus, poor readers had more opportunities to consider the selection of textual manipulations.

Table 3 Means and standard deviations for Comprehension subtest: Nelson Reading Skills Test

Reading Ability	Treatment: Off line	Treatment: Test only	Treatment: Select options	Treatment: All options
Good Readers				
M	32.1	32.1	33.5	33.9
SD	3.1	3.6	2.5	3.1
Poor Readers				
M	25.5	19.7	18.5	23.4
SD	5.6	7.5	7.7	5.8

Note. Maximum score = 38. $n = 13$ for each cell.

Table 4 Options selected by subjects in the select-options treatment

	Options					
	Vocabulary	Easier Version	Background	Main Idea	Reread	Total
Good Readers						
n	36	44	49	38	14	181
Probability	.20	.24	.27	.21	.08	1.00
Poor Readers						
n	56	52	59	50	30	247
Probability	.23	.21	.24	.20	.12	1.00

Note. Values based on selections by 13 good and 13 poor readers across six passages.

A chi-square was computed to test for preferences among the five categories of textual manipulation available in the select-options condition. The analysis revealed no significant differences in selections between good and poor readers on the five possible options for textual manipulations, $\chi^2(4, N = 428) = 3.22, p > .05$. The chi-square for selections across reading ability, however, indicated significant differences between the number of choices for each category of manipulation, $\chi^2(4, N = 428) = 28.23, p < .001$. Finally, the number of selections in each category of textual manipulation was individually compared to an aggregate of all the other options selected. Five separate chi-square analyses were generated from five null hypotheses which stated that no difference existed between the selection of one category of textual manipulation and the remaining four categories (Edwards, 1969). These analyses revealed that additional background information was requested significantly more often, $\chi^2(1, N = 428) = 7.05, p < .001$, and rereading was requested significantly less often, $\chi^2(1, N = 428) = 26.17, p < .001$, than other options.

These data reveal that subjects given the opportunity to do so, independently chose to select textual manipulations mediated by the computer and that across all six passages subjects chose the background manipulation more often and rereading (at least after initial reading and study) less often than other manipulations.

Trials to Criterion

To further explore the effects of computer-mediated manipulations of the text, means for the number of trials to criterion were compared. Each subject was required to obtain a score of at least 4 correct out of 6 on the comprehension items before continuing to the next passage. For practical reasons off-line subjects were given the next passage automatically if their third trial was not successful. On-line subjects could choose to continue or to try reading and studying the passage again after their third failure. To standardize this measure across experimental conditions, a failure on the third trial was recorded as four trials to criterion regardless of the number of attempts made after this trial. Means and standard deviations for trials to criterion by experimental group, reading ability, and passage difficulty are given in Table 5.

Although this measure is not independent of scores achieved on the first trial, it does permit a more direct comparison of reading under conditions permitting textual manipulations (select options and all options) and those more typical of normal text (off line and test only). If textual manipulations were beneficial in helping a subject comprehend the text, some of the benefit may be realized only after a subject is convinced that they are needed to enhance comprehension by virtue of an initial failure to meet the criterion score.

A three-way, mixed-factorial ANOVA was computed on means for the number of trials to

Table 5 Means and standard deviations for trials to criterion

	Treatment							
	Off line		Test only		Select options		All options	
Text Difficulty	Low	High	Low	High	Low	High	Low	High
Good Readers								
M	4.0	4.7	5.8	5.1	6.1	4.7	3.7	3.8
SD	1.8	1.7	2.9	1.8	2.6	2.3	1.4	1.3
Poor readers								
M	7.8	8.7	10.8	10.2	9.6	9.1	8.4	6.8
SD	3.2	2.6	1.5	1.9	2.4	2.7	2.8	2.2

Note. Maximum number of trials = 12. n = 13 for each cell.

criterion. This analysis revealed significant main effects for treatment, $F(3, 96) = 7.86$, $p < .001$, and reading ability, $F(3, 96) = 130.41$, $p < .001$. A Newman-Keuls test of all pairwise comparisons between treatments yielded a statistically significant difference between the all-options and test-only treatments. In addition, Scheffé's comparison procedure was used to compare means for the off-line and test-only conditions to means for the select-options and all-options conditions. This comparison was nonsignificant, $p > .05$.

These data complement the finding that the all-options subjects scored higher on the comprehension items after the first trial. Subjects in the all-options condition scored higher on their initial attempt on the comprehension items *and* required fewer trials to meet the criterion score. The availability of computer-mediated textual manipulations alone, however, does not appear to account for this difference. Subjects in the select-options condition did not require significantly fewer trials when compared to conditions in which manipulations were unavailable (off line and test only). The difference in the mean number of trials to criterion between groups with options for help (select options and all options) and groups without options for help (off line and test only) was also nonsignificant. These findings suggest that under the conditions of the present experiment computer control of manipulations was more effective than simply making manipulations available for reader selection.

Discussion

Findings suggest that the comprehension of intermediate-grade good and poor readers can be affected by providing textual manipulations mediated by a computer. The interpretation of these effects is constrained, however, by unanticipated interactions and the performance of on-line subjects when compared to subjects reading passages off line.

In response to the hypotheses which guided this study, results indicate that the comprehension of a particular set of expository texts can be affected by variations in textual manipulations mediated by a computer. However, this effect appears to be more a function of using the computer to control the reader's exposure to textual manipulations rather than simply making textual manipulations available for reader selection.

For both high- and low-difficulty passages subjects who were required to view all of the available manipulations obtained scores which were significantly higher than on-line subjects who had no manipulations available. The advantage of the all-options subjects was also more pronounced for high-difficulty passages

in that for these passages they scored significantly higher than subjects in the select-options condition. Although end-of-passage scores were higher for the select-options group than for the test-only group, these differences were not statistically significant. The lack of a statistically significant difference on the trials-to-criterion measure between conditions with and without textual manipulations (off line and test only vs. select options and all options) also supports the notion that computer control accounted for the superior performance of the all-options subjects.

These results can be interpreted in light of metacognitive theory and technological attributes of the computer which may be employed to mediate text. Perhaps intermediate-grade readers, as metacognitive theory suggests, are less adept at managing the contingencies of their reading and study and therefore benefited from the external control provided by the computer. As is suggested by the data in this study, this conclusion is more strongly supported when text is more difficult. This interpretation suggests that the computer might provide unique opportunities to manage a reader's interactions with text during independent reading.

Using the computer in the select-options and all-options conditions may have encouraged readers to process more deeply the meaning of the text by structuring their exposure to designated textual manipulations. Additionally, the computer may have helped readers monitor their comprehension by externalizing processing variables which some readers ordinarily ignore. Because a minimum study time was imposed on subjects in the all-options treatment, the likelihood of meaningful interactions with the text was also increased. Further research is needed to investigate these possibilities.

There is no evidence that the relatively limited exposure to computer-mediated text in this study had any positive effect on a general measure of reading comprehension. In fact, the mean test scores on a postexperimental standardized test of reading comprehension indicated that poor readers in the select-options condition had significantly lower scores than did poor readers in the off-line condition. Because this finding is problematic from a theoretical standpoint, more research is needed to determine if this is a spurious finding or whether computer-mediated text under some conditions may interfere with the comprehension processes of poor readers.

Conclusions drawn from a comparison of the three on-line treatments require qualification when the performance of the off-line group is taken into account. On high-difficulty passages the performance of the off-line group was consistent with the test-only condition which also did not permit textual manipulations. The unexpected interaction between passage difficulty and experimental condition, however, reflects the fact that on low-difficulty passages the mean score of the off-line group was significantly higher than both the test-only and select-options groups (see Figure 1). Apparently, comprehension of low-difficulty text under the conditions of this study is achieved as well or better when reading text off line as opposed to reading under any of the on-line conditions.

This conclusion invites further speculation in that the only difference between the off-line and test-only conditions was whether the text was presented by the computer or the printed page. One explanation may be that the novelty of reading text which was mediated by a computer interfered with comprehension processes on low-difficulty passages. The fact that most subjects in this study had never used a computer before contributes to this possibility. Conversely, interest in reading generated by this novelty might explain the fact that on-line subjects scored higher on the more difficult passages. Interest has been shown to be an important variable in reading comprehension (Asher, 1979) and in predicting the readability of text (Klare, 1984).

Finally, evidence in the present study suggests that both good and poor intermediate-grade readers may be prompted to interact with the meaning of expository text when the computer is used to mediate a selected set of textual manipulations. Data collected by the computer during the reading and study of subjects in the select-options condition indicate that these

readers attempted to enhance comprehension by freely selecting textual manipulations mediated by the computer. For reasons which are difficult to determine from the present study, subjects requested background information significantly more often and rereading significantly less often than other textual manipulations. The difference in the mean proportion of manipulations selected when compared to number of test attempts between high- and low-difficulty passages suggests, however, that subjects' selections were at least partially guided by their comprehension needs.

In sum, the present study points to potential applications of computer technology in mediating written text in ways which may affect comprehension. Because the printed page has been the dominant medium for representing text-based information since the inception of written communication, a consideration of alternative media has not been relevant to research into reading and learning from text. The advent of computer technology and the capability to achieve previously unavailable manipulations of print may, however, significantly affect typical reading behavior and the processing of written text.

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Footnote

[1]Copies of the software used in this study may be obtained by contacting the first author.

APPENDIX

Pots and Pans (original high-difficulty passage)

Pots and pans were once considered to be precious possessions. In the fourteenth century, during the reign of Edward III of England, the pieces of cookware—iron pots, griddles, spits, and frying pans—were numbered among the king's jewels. They were difficult to come by and, being rare, were extremely valuable; when the monarch went on a journey or made a visit, the pots and pans traveled along in a separate coach.

By the time Henry V, Edward's grandson, ascended the throne in the following century, the royal frying pans were made of silver, and so were the roasting spits.

The kettles at Westminster during the early sixteenth century, when Henry VIII held the throne, were "copper-gilt" and quite lavishly decorated with chasing. The handles of the cooking ladles were chased with the royal arms, and one of the two-pronged toasting forks is known to have been topped with an ornate metal ball.

Pots and Pans (revised version)

Many years ago few people had pots and pans. Because there were so few pots and pans, they were very dear to people who owned them. They were as valuable as jewels. That is what Edward the Third thought. He was king of England in the 14th century. Edward's iron pots and pans even went with him on trips. They traveled in their own coach.

Edward's grandson, Henry the Fifth, became king in the 15th century. His kitchen now had cookware made of silver.

In the 16th century Henry the Eighth was king. In his home at Westminster his kettles were covered with copper. The cookware was now covered with beautiful decorations. Beautiful lines were cut into the metal. Even the handles of scoops were decorated this way. A picture that stood for the king was cut into each handle. The end of one roasting fork was also decorated with a fancy ball.

Sample comprehension item

In the 16th century what made the king's cookware different from earlier cookware?

1. It was made of silver.
2. It was more greatly decorated.
3. It was now kept in the kitchen.
4. It was no longer owned by the king.

(The correct response is 2.)