find information (example of the use of an INTERACTIVE model); and searching with an advisor, in which the learner is couched by an advisor and the program changes depending on the user's current position of inquiry and study (example of the use of a PROACTIVE model).

The advanced technologies available today allow designers to explore different ways to present information to the learner. Researchers discovered that differences in learner characteristics and the goal of instruction can help to determine the type of interactivity to implement. Designing programs which can meet the individual needs of a large group of learners and can be modified depending on the goal of instruction will prove beneficial.

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Differences Between Electronic and Printed Texts: An Agenda for Research

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Abstract The author reviews the literature relevant to comparing electronic and printed texts and he argues that the critical differences emerging from his review are conceptual not visual. Further, he argues that an awareness of these conceptual differences should guide researchers and designers interested in computer-based instructional materials. The author's argument is based on a bifurcation of the research examining differences between printed and electronic texts: (a) convergent studies in which differences in the textual display are minimized and (b) divergent studies in which the capabilities of the computer are used to present texts in ways not easily replicated in print. Four critical differences based on theoretical positions and findings from divergent studies are identified: (a) electronic texts can control readers' access to text; (b) electronic texts permit readers and texts to interact; (c) electronic texts can be structured differently than printed texts; and (d) electronic texts make available a wide range of symbolic elements that can be integrated with written prose. A discussion of each difference includes examples of relevant research questions.

Computer-based instructional materials frequently include textual information displayed electronically on a CRT screen. The appropriate use of electronic texts has been a concern in the design of such materials (e.g., see Rubens & Krull, 1985). Implicit in this concern is the assumption that electronic texts are different from printed texts. Few would argue with the intuitive notion that electronic texts have characteristics distinguishing them from printed texts and that these characteristics ought to be taken into account when designing computer-based instruction. However, the extent and nature of these differences is ill-defined, ranging from a focus on visual aspects of the display such as how much text should be displayed on a single screen (e.g., Merrill, 1985) to a focus on conceptual differences such as those associated with hypertexts (e.g., Jonassen,1986).

A number of research studies have investigated the characteristics of electronic texts. However, because this research literature encompasses a broad range of issues and questions, the critical differences between electronic and printed texts may not clearly emerge from a review of that literature. One purpose of this paper, therefore, is to identify more clearly the critical differences between printed and electronic texts by categorizing existing research emphases and by summarizing the results of the research within these

categories. In addition, several theoretical perspectives are outlined that may be useful for interpreting previous research, for setting priorities for future research, and for guiding the use of electronic texts in computer-based instructional materials.

A second purpose is to forward the thesis that the critical differences between printed and electronic texts are primarily conceptual rather than visual. Conceptual differences are argued to be more critical because they identify electronic texts as fundamentally different from printed texts and because their influence on learning from texts is more direct and potentially more powerful. Thus, designers of computer-based materials who understand these important conceptual differences will be more able to employ electronic text effectively to enhance learning. Understanding the conceptual differences between electronic and printed texts will also contribute to the development of new conventions for writing and reading electronic texts.

A Bifurcation of the Research Literature

To derive the critical differences between electronic texts and printed texts from the research literature, it is perhaps useful to divide that literature into two main types along the lines suggested by Reinking and Bridwell-Bowles (1991). They categorized research studies as being either convergent or divergent depending on whether electronic texts were viewed in terms of printed texts (convergent) or whether they were viewed as essentially different from printed texts (divergent).

Convergent Research

In convergent studies, electronic texts tend to be viewed as extensions of printed texts. That is, texts displayed by a computer are viewed as printed texts that have been converted with minimal changes into an electronic display. This perspective leads to research questions that focus on the visual characteristics of electronic texts, such as the size of the CRT screen and the resolution of texts displayed on it. References to electronic texts in terms analogous to printed texts is another characteristic of convergent studies. The analogies may be explicit—such as when a screen is considered analogous to a printed page—or they may be implicit, such as when flashing a portion of the text is assumed to serve the same function as underlining a text or printing it in boldface or in italics. Characteristics of electronic texts investigated in convergent studies include scrolling versus "windowing" of texts (Bury et al., 1982), optimal screen size (Duchnicky & Kolers, 1983; Yeaman, 1987), fill justified text on computer screens (Trollip & Sales, 1986), all-capital versus upper- and lower-case letters (Henney, 1983), and automatic phrasing of texts (Jandreau, Muncer, & Bever, 1986).

Other convergent studies make a direct comparison between electronic and printed texts. In these studies the electronic textual display reproduces as closely as possible a printed version of the same text. The nature of these studies is typically exploratory, investigating whether often unspecified characteristics inherent to electronic texts may affect reading performance. They are generally atheoretical and frequently lack specific *a priori* hypotheses, substituting instead general questions about how reading performance varies along one or more dimensions.

In general, these studies can be grouped according to their dependent variables. For example, several researchers have investigated whether reading rate is affected when a text is displayed on a CRT screen as opposed to on printed pages (Gould & Grischkowsky, 1983; Haas & Hayes, 1985a, 1985b; Hansen, Doring, & Whitlock, 1978; Kruk & Muter, 1984; Muter, Latremouille, Treurniet, & Beam, 1982). Other researchers have focused on whether closely matched printed and electronic texts effect differences in reading comprehension (Fish & Feldman, 1987; Gambrell, Bradley, & McLaughlin, 1987). Related comparisons involving printed and electronic texts include proofreading accuracy and speed (Wright & Lickorish, 1983, 1984) and performance on a standardized test presented on- or off-line (Heppner, Anderson, Farstrup, & Weiderman, 1985). Research investigating whether electronic texts produce harmful physiological effects might also be included with convergent studies (e.g., see the research summarized by the National Research Council, 1983).

Although the findings from the convergent studies are mixed, some general conclusions can be supported. Overall, there is little reason to believe that reading performance is changed significantly when texts are presented electronically in a form that varies minimally from printed texts. This conclusion is consistently supported in studies comparing reading comprehension. In the convergent studies cited here as well as those that have treatment conditions matching parallel electronic and printed texts (e.g., see Reinking, 1988), there is a consistent finding of no statistically significant differences on measures of reading comprehension.

On the other hand, studies examining reading rate suggest that electronic versions of printed texts are read more slowly than comparable versions displayed on CRT screens. However, in most instances the slower rate of reading electronic texts is linked to the constraints of the particular hardware and software used to display the text (e.g., the size of the CRT; cf. Haas & Hayes, 1985a, 1985b), the inability to make notations during reading (cf. Wright & Lickorish, 1983, 1984), or the amount of experience subjects have had in reading electronic texts (e.g., Kuntz, Schotz, & Hovekamp, 1987; Heppner et al., 1985). Consistent with these explanations is that differences in reading times are more often significant when the experimental texts are lengthy (cf. Muter et al., 1982; Reinking, 1988). In other words, there is no strong evidence indicating that the longer reading times associated with electronic texts is a consequence of enhanced or depreciated processing during reading (see Mitchell, 1984, for a discussion of reading time as an indicator of underlying cognitive processing).

Similarly, studies investigating the effects of varying electronic textual displays (e.g., scrolling vs. windowing) have indicated that such variations may affect reading rate and efficiency, yet, overall, there is little evidence that these factors significantly affect the learning or recall of textual information. These studies, and the results obtained thus far, parallel the research on typography and related visual aspects of printed texts that were carried out in earnest during the 1930s and 40s (see Daniel & Reinking, 1987). Similarly, current research focusing on the visual display of electronic texts may be subject to the same limitations associated with the research on typography in printed texts (see Waller, 1991). Not the least of these limitations is that publishers of instructional materials do not typically follow the recommendations from this research, preferring instead to follow their own intuitions or accepted practice.

Divergent Research

In divergent studies, electronic texts are viewed as possessing unique characteristics that clearly separate them from printed texts. These characteristics are seen as potentially important for influencing reading in ways not possible or feasible when texts are presented

in conventional printed forms. Divergent studies focus on conceptual differences between electronic and printed texts instead of on the visual differences that are typically the focus of convergent studies. In other words, divergent studies focus on alternative formats for communicating textual information rather than on the physical appearance of electronic texts. Consistent with their focus on conceptual differences, divergent studies typically examine dependent variables related to comprehension and learning rather than to other indicators of reading performance such as reading rate. Similarly, divergent studies tend to investigate electronic textual formats that proceed from explicitly-stated theoretical positions.

Across divergent studies, the formats and uses of electronic texts vary considerably based on factors such as the capabilities of the hardware and software used, the theoretical perspective guiding the research, and the interests of individual researchers. Some examples of the various uses of electronic texts in divergent studies include modifying texts during reading in response to specific reading behaviors (L'Allier, 1980), providing computer-aided glosses to textual information (Blohm, 1982), providing optional or mandatory assistance for comprehending a text (McConkie, 1983; Reinking, 1988; Reinking & Schreiner, 1985), requiring the review of relevant text after an incorrect response to an inserted question (Alessi, Anderson, & Goetz, 1979; Reinking & Pickle, 1990; Tobias 1987, 1988), and providing context-specific assistance with unfamiliar words during reading (MacGregor, 1988a, 1988b; Reinking & Rickman, 1990).

A conclusion clearly supported by the results of divergent studies is that new formats for presenting texts electronically with the aid of a computer can increase comprehension and learning when compared to conventional printed texts. A few of these studies shed light on how divergent electronic texts affect specific components of reading and learning as well as what factors account for the differences observed. For example, in several divergent studies, readers have had various options for assistance while reading electronic text, including relatively easy access to context-specific definitions of unfamiliar words. By focusing exclusively on this feature, Reinking and Rickman (1990) found that readers of electronic texts investigated the meanings of more words than readers reading printed texts accompanied by a dictionary or glossary. Likewise, readers of the electronic texts scored higher on posttests designed to measure passage comprehension and their understanding of the difficult words in the passage.

Some divergent studies suggest that electronic texts employing the unique capabilities of the computer may affect important underlying processes directly related to reading comprehension. For example, Reinking (1988) investigated whether increased comprehension among readers having various computer-based assistance available during reading was due to the greater time these readers spent reading the experimental texts when compared to readers reading the same texts on printed pages. When reading time was controlled statistically, a significant effect in favor of the readers reading the electronic texts remained, indicating that qualitative differences in processing the textual information, not just quantitative differences in the time spent reading, accounted for increased comprehension of the text. Likewise, studies investigating the mandatory review of relevant text after a reader incorrectly responds to an inserted question suggest that versions of electronic texts can affect readers' metacognitive strategies during reading (cf. Reinking & Pickle, 1990; Tobias, 1987, 1988). Apparently, during mandatory review of previously-read text, readers tend to focus their attention disproportionately on portions of the text relevant to the question missed unless their review is followed by a different question.

The Relative Importance of Convergent and Divergent Research

Convergent and divergent studies comprise legitimate areas of inquiry that may provide useful information to designers of computer-based instructional materials. However, the results of research conducted thus far suggest that divergent studies deal with the more critical differences between electronic and printed texts. In divergent studies, electronic texts consistently affect comprehension and learning, but in convergent studies they do not.

Although divergent studies in general may be more important from the standpoint of identifying critical differences between electronic and printed texts, some convergent studies may provide more useful information than others. For example, Wright (1987) has argued that it may be unproductive to compare visual aspects of textual displays across media. That is, comparing an electronic text displayed on a high-resolution CRT to a printed text on a blurred photocopy provides little insight about either medium. Instead, she advocates comparing various electronic textual displays to discover their most relevant visual characteristics irrespective of comparable printed texts. Similarly, convergent studies based on well-defined theoretical positions are more likely to produce useful findings. Because convergent studies tend to focus on visual elements of textual displays, theoretical positions might be derived from the research literature on the typography of printed texts (e.g., see Daniel & Reinking, 1987; Waller, 1991).

Although the existing research suggests that the critical differences between electronic and printed texts may be found in divergent studies, the diversity of electronic texts across studies is an obstacle to identifying clearly what these differences are. A clearer understanding of the critical differences emerge, however, from the theoretical positions associated with divergent studies.

Differences Derived from Theoretical Positions

Several theoretical positions aimed at identifying the important characteristics of electronic texts have been proposed. These theories focus attention on characteristics of electronic texts that may affect reading and learning. Theoretical speculation is important because it assists researchers to formulate testable hypotheses related to diverse applications of electronic texts, which can in turn lead to generalizations that can guide the use of electronic texts in computer-based instructional materials.

The intent of this paper is not to provide a detailed review of major theoretical positions. Instead, theoretical positions are highlighted under four statements, each of which identifies a unique characteristic of electronic texts and which is derived from current theory and research. Illustrative examples from research and instructional materials are also presented.

Electronic Texts Can Control Readers' Access to Text During Independent Reading

Wilkinson (1983) has argued that the fundamental difference between electronic and printed texts is that text on a computer screen is displayed as if through a window revealing only a portion of a text (see also Bolter, 1991). Other portions of the text not revealed in the window may or may not be available depending upon the contingencies of a computer program controlling the textual display. In other words, a computer programmer decides when and under what conditions readers may access portions of the text. On one hand, the reader may be given almost unlimited access to the various portions of a text; on the other

hand, a reader may be greatly restricted from accessing certain portions of the text until specific conditions prevail. In addition, the unit of text controlled by the computer can be as small as a letter on a single screen or as large as sections requiring multiple screens.

The capability to control flexibly what textual units are displayed and when they are displayed to a reader is a distinguishing feature of electronic texts. This capability suggests new variables that might be the object of empirical study. For example, Wilkinson (1983) has suggested that framing and pacing are new conceptual variables to be considered when texts are displayed electronically. Similarly, Daniel and Reinking (1987) have argued that decisions about displaying printed texts have always been two-dimensional. That is, attempts to assist a reader in comprehending a printed text during independent reading revolve around cues that are limited to two-dimensional space. They have pointed out, however, that time is a third dimension in electronic texts. *When* to display a portion of the text becomes as important as *where* it will be displayed.

Researchers have begun to examine the implications of controlling a reader's access to textual information. For example, Reinking (1988; Reinking & Schreiner, 1985) has compared readers' comprehension when computer-based assistance during reading was mandatory vs. self-selected. Findings have been mixed, indicating that more research is needed to clarify the conditions under which access to textual information should be controlled by the computer or by the reader. These and similar studies represent new areas of inquiry in that they examine conditions not easily duplicated during the independent reading of printed texts.

Other studies illustrate how controlling textual access opens up new areas of inquiry that extend established areas of research on printed texts. For example, research on the effects of inserting questions in electronic texts (Reinking & Pickle, 1990; Tobias, 1987, 1988) extends more than two decades of published research investigating the effects of questions inserted in printed texts (see major reviews by Anderson & Biddle, 1975, and Hamilton, 1985). Inserted questions serve a different function when used in electronic texts and thus new research questions emerge. For example, in electronic texts an incorrect response to an inserted question may trigger the display of text relevant to the item missed. Readers can be required to review that portion of the text until they can respond correctly to the inserted question. Thus, investigating the effects of mandatory review on reading performance is related to previous research on inserted questions but it is also a new area of research associated with the capability of the computer to control readers' access to text.

Instructional applications involving computers have employed the capability of electronic texts to limit readers' access to text. For example, *The Puzzler* (1984) is a computer-based reading activity resembling an instructional activity referred to as the Directed Reading-Thinking Activity or DRTA (Stauffer, 1969). In the DRTA, a teacher asks students to make predictions about what a reading selection will be about and then asks them to read the first section of the text. When they are finished reading, the teacher asks students to evaluate their initial predictions and to make new ones for the next section of the text. This cycle is repeated several times until the end of the selection. The rationale for this activity is to engage students in the active processing characteristic of successful reading; that is, during reading good readers typically form initial hypotheses, which are either confirmed or rejected and replaced by new hypotheses. Using conventional printed materials, it is difficult to imagine how such an activity could be carried out without the intervention of a teacher. Even when a teacher is leading the activity, one problem frequently experienced is that students reading to the end of a specified section may be tempted to read further while they are waiting for other students to finish reading. *The Puzzler*, on the other hand, because

it employs electronic texts, enables a similar activity to be carried out when students are reading independently. Readers using the program are shown a segment of the text and required to enter or revise their predictions before being allowed to see the next portion of the text.

Electronic Texts Permit Readers and Texts to Interact

The act of reading any text is frequently referred to as an interaction between the text and the reader. However, there is an important difference between electronic and printed texts when discussing reading as an interactive process. For printed texts, reading can be interactive only in the sense that two separate factors must be considered to explain comprehension. That is, the understanding of a text is the product of a stimulus in the form of printed words and the internal cognitive processes brought to bear by the reader. The result—comprehension, or the lack thereof—is therefore an interaction in a statistical sense. That is, the degree to which a particular text may be comprehended is the result of an interaction between factors within the reader (e.g., the availability of relevant background knowledge and metacognitive skills) and factors external to the reader (e.g., features of the text such as coherency, adjunct aids, organizational cues, etc.). The only sense in which the on-going process is interactive is that readers may be interacting with their own knowledge and cognitive skills. Printed texts are inert and cannot respond to a reader during reading. To refer to reading printed materials as an interaction between a text and a reader may highlight the role of a cognitively active reader in explaining comprehension, but it does not describe literally what occurs during the reading.

Reading electronic texts, however, may entail a literal interaction between a reader and a text. For example, based on a reader's characteristics or actions, electronic texts can adapt and respond during the act of reading a text. The computer makes it possible to monitor an individual reader's characteristics and actions and to effect a wide range of appropriate responses based on this information. A clear example of this capability is L'Allier's (1980) study in which texts were modified during reading based on a complex algorithm that included subjects' reading times and their accuracy and response times to inserted questions. He found that high school students who were poor readers but who read the adaptive text performed as well as good readers reading texts that did not adapt to a particular reader's needs. In the future, a wide range of diverse input might be employed to adjust the difficulty or other factors of electronic texts. For example, an imaginative type of electronic text might use physiological measures such as galvanic skin response to indicate a reader's anxiety and to adjust texts accordingly. Although such an application may appear fanciful, it illustrates the range of input that might be used to shape the interaction between a particular reader and a particular text.

Several writers have elaborated on the capability of computer-mediated texts to effect a literal interaction between readers and texts during reading (see Daniel & Reinking, 1987; Duchastel, 1988; Reinking, 1987). Additionally, a growing number of research studies have begun to examine the effects of having subjects read electronic texts interactively (Blohm, 1982, 1987; MacGregor, 1988a, 1988b; Reinking, 1988; Reinking & Schreiner, 1985; Tobias, 1987). Preliminary findings suggest that interactive electronic texts increase comprehension. However, additional research is needed to clarify why this seems to be the case. For example, it has been proposed that confronting readers with decisions about seeking assistance during their reading of electronic texts may increase their level of metacognitive activity (see Reinking, 1988; Reinking & Schreiner, 1985).

A wide range of instructional computer programs have increasingly made use of electronic texts that have interactive features. A typical example is *The Bartlett Saga Series,* a social studies simulation as described by Willing (1988). The object of the activity is for students to play the roles of various members of the Bartlett family during several periods of Canadian history. Text and graphics are supplemented with several functions represented by icons on the screen and available to students while they are engaged in the simulation. For example, students can seek help with unfamiliar words, research background information from a data base, leave messages for others using the program, and read messages from previous users. *The Comprehension Connection* (1987) is another instructional program that uses the interactive capabilities of electronic texts but that is directed specifically at enhancing readers' comprehension abilities. This program presents texts supplemented by various options available for use when readers experience comprehension difficulty. Options for assistance include the definitions of unfamiliar words, additional background information, the structure of the textual information, and an easier less-technical version of the original text. Additionally, readers are required to consider these options again in conjunction with the text when they fail to achieve a criterion score on a comprehension test. This feature illustrates how the capability to control readers' access to text may also be used interactively in electronic texts.

Computer-Mediated Texts May Be Structured Differently than Printed Texts

According to Bolter (1991), all writing throughout history has been shaped by the nature of the available writing space; he defines writing space as "the physical and visual field defined by a particular technology of writing" (p. 11). The writing space, defined by a technology of writing, in turn produces hard and soft structures. Hard structures are "the tangible qualities of the materials of writing" (p. 41) such as the pages of a book or the hardware associated with computers. Soft structures emerge from the characteristics of the hard structure. In the case of printed materials, the soft structures are pages, paragraphs, chapters, punctuation marks, and related features. Soft structures tend to become internalized as components of the schema and strategies used by readers and writers to deal with the structure of texts. Bolter argues that electronic texts have hard structures radically different from any previous writing technology and thus they inspire new soft structures as well.

Similarly, Duchastel (1986) has highlighted structural considerations when comparing printed and electronic texts. He has argued that informational texts can be semantically structured or format structured. In semantically structured texts, such as a psychology textbook, information is structured hierarchically in highly interrelated units. Semantically structured information does not readily accommodate individualized searches for information because a unit of information is highly dependent on what information comes before or after it. In format-structured texts, such as an airline schedule, information is organized into heterarchical units that are more independent and that permit more individualized searches for information. In printed materials, the nature of the information dictates which type of structure will be selected. For example, it is difficult to imagine a psychology text organized like an airline schedule, and the reverse would be at least inefficient. However, the ability of computers to help readers locate information quickly and to relate diverse units of information in complex non-linear structures suggests that the structure of electronic texts can be much more fluid regardless of the type of information presented.

Numerous developers of computer-based instructional materials have experimented with non-linear forms of electronic texts, which have come to be grouped under the rubric of hypertext (see Jonassen, 1986; Weyer, 1982). Applications of hypertexts have ranged from conveying purely expository information to experimenting with new forms of literature and poetry (see Bolter, 1991). A defining attribute of hypertexts is that they embed textual information in related but non-sequential segments and they provide mechanisms for readers to explore this information flexibly, often on the basis of their personal preferences and needs. Hypertexts vary as to the degree that separate elements are interrelated as well as the degree to which readers are free to explore these relations. There is some evidence that hypertexts are becoming one of the soft structures associated with electronic texts. For example, several popular authoring languages such as Hypercard for the Macintosh and Linkway for MSDOS machines seem to encapsulate hypertextual principles. The structural components of these languages seem to be becoming the internalized metaphors for conceptualizing electronic texts.

Despite the wide-spread enthusiasm for developing hypertexts, there has been relatively little empirical research devoted to investigating their effects on aspects of reading and learning. An issue raised repeatedly in the literature concerning hypertexts is the potential difficulty readers may face in finding their way through a complicated maze of information without becoming hopelessly lost or overwhelmed (see Dede, 1988; Kerr, 1987; Yankelovich, Meyrowitz, & Van Dam, 1985). Some preliminary findings reported by Spiro et al. (1988) suggest another direction for research involving hypertexts. He found that when dealing with ill-structured knowledge pertaining to diagnoses, medical students recalled more information when reading conventional printed texts than when exploring flexibly the same content presented in a hypertextual format. However, those students reading the hypertext were better at applying the information when carrying out diagnoses. These findings are similar to those reported by Mannes and Kintsch (1987) in which readers shown an outline inconsistent with a text that they subsequently read recalled less literal information but were able to apply the information better than readers shown a consistent outline before reading. These examples suggest a new set of research questions concerning how variables such as content, organizational structure, and learner characteristics affect comprehension and learning in hypertexts.

Electronic Texts Make Available a Wide Range of Symbolic Elements that Can Be Integrated with Written Prose

According to Salomon (1979), instructional media can be distinguished on the basis of the symbol systems available for conveying information. The symbol systems available are directly related to the technological attributes of a medium. Starting from these assumptions, Reinking (1987) has argued that electronic and printed texts should be considered separate media.

Although the symbolic elements that distinguish electronic and printed texts can be directly related to conceptual differences such as those discussed thus far, they can also have an extra-textual dimension. In printed texts, the primary domain of symbolic elements that might be considered extra-textual are those associated with graphic aids such as tables, diagrams, and illustrations. These graphic aids may be included for amplification, clarification, or interest, but they are usually considered to be separate from and subordinate to the texts they accompany.

There are comparable elements in electronic texts. However, in electronic texts there are more elements from which to choose and more ways to think about using them. For example, it is not usually practical or feasible to incorporate sound effects, animation, and live-action video into the presentation of printed texts, but these and similar symbolic elements are relatively easy to incorporate into electronic texts and they are becoming increasingly common in a wide range of computer-based materials. Like the prose they accompany, these elements of electronic texts are more dynamic and interactive. More importantly, their role is less ancillary to the prose. In fact, Bolter (1991) has argued that in electronic texts, "pictures and verbal text belong to the same space, and pictures may cross over and become textual symbols" (p. 72).

Little research has addressed the unique symbolic elements that can be integrated into electronic texts. A few studies have examined computer-generated graphics, but these studies are aimed primarily at providing guidelines for instructional designers who wish to integrate graphics into computer-based instructional programs (see Alesandrini, 1987, for a review). These studies would be classified as convergent in the scheme introduced earlier in this paper, because they view computer-generated graphics as serving a function analogous to the graphic aids accompanying printed texts.

Many current examples could be used to illustrate how a wide range of symbolic elements are being integrated with prose into electronic texts. For example, graphical interfaces employing icons as a type of picture writing are quickly becoming a standard feature of electronic texts. Likewise, in many instructional computer programs, it is common to see prose and related graphical content more closely juxtaposed than in printed texts. In fact, graphical information and texts tend to be merged rather than used as separate structural units. For example, in electronic texts there is little need for a convention analogous to a caption under a picture as is the case in printed texts. Graphical content and the prose to which it relates is more fluid in electronic texts, thus eliminating the need for a separate segment of prose to explain a graphical representation. For example, in a printed text, one might encounter a series of separate drawings illustrating the stages of a process. In an electronic text, the same process could be illustrated on a single screen in which the computer graphic could be animated to illustrate changes in each stage of the process. Explanatory prose could fade in and out of the screen in a manner that is coordinated with the visual changes in the computer graphic. Research is needed to investigate the effects that the use of such symbolic elements have on reading and learning.

Summary and Conclusions

The research literature most relevant to identifying the critical differences between printed and electronic texts can be divided into two types: convergent studies and divergent studies. In convergent studies, electronic texts are viewed as essentially printed texts that have been displayed in a different visual medium yet in a manner directly analogous to conventional printed materials. Convergent studies are typically atheoretical. In divergent studies, on the other hand, electronic texts are viewed as conceptually different from printed texts. The applications investigated purposefully diverge from conventional printed materials usually on the basis of theoretical perspectives suggesting how electronic texts might influence higher-level reading processes.

The results across studies suggest that the type of applications characteristic of divergent studies affect comprehension and learning while convergent studies typically do not. Therefore, researchers and instructional designers interested in pinpointing the critical differences between electronic and printed texts would profit more by attending to the conceptual differences defined by divergent studies. Researchers interested in pursuing questions along the lines of convergent studies need to consider the possibility that such research may be most productive when it focuses exclusively on electronic texts and when it is based on well-articulated theoretical positions.

An examination of the theoretical positions associated with divergent studies reveals a tentative list of critical differences between electronic and printed texts. This list could be used to guide researchers interested in electronic texts as well as the designers of computer-based instructional materials who wish to use such texts effectively. Critical differences were highlighted by identifying four characteristics of electronic texts: controlled textual access, interactive capabilities, unique structural formats, and a wide range of symbolic elements that can be integrated with prose. These characteristics provide a foundation for developing a research agenda for investigating how electronic texts may affect reading and learning.

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Hypermedia: A Conceptual Framework for Science Education and Review of Recent Findings

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Abstract An attempt has been made to provide a conceptual and theoretical framework for the use of hypermedia presentations in the classroom, particularly in the science classroom. Traditional methods of presenting information were linear in nature, but research has shown that learning rarely proceeds in a linear fashion. The omni-directional nature of hypermedia presentations fit well into the models of learning of some of the most recent cognitive theories. They have been particularly well suited to several important needs for science education. These topics are discussed in relation to the preliminary findings of some ongoing research projects at Vanderbilt University.

Introduction: What Is Hypermedia?

In order to understand the concepts of hypertext and hypermedia, it may be helpful to consider the analogy to printed documents presented by K.E. Smith (1988). Authors often use footnotes, endnotes, sidebars, and bibliographies to refer their readers to related materials and to incorporate additional information that has a bearing on their article or topic. This idea of linking information that is related is the basis for hypertext and hypermedia systems. In a sense, it is nothing new, because authors of printed literature have been doing it for years. Anyone who has read an article in an encyclopedia is familiar with the list of related topics at the end and has tried at one time or another to trace a theme through a series of footnotes, endnotes, and external sources.

What is new about hypermedia is that it is an attempt to provide a method of linking information and concepts without requiring the user to physically leave the environment in which he is working in order to follow those links. It is designed using computer software which allows the author to create a network of interconnected electronic cards, or screens, in such a way that they represent a collection of related ideas, and organize, store, and retrieve information (Halasz, Moran & Trigg, 1987). Each screen is thought of as a *notecard* or *page*, and instead of sidebars and footnotes, the user is provided with *buttons* that allow him to branch to related ideas, information, and concepts. This link might take him to