Multimedia Textbooks and Student Learning

Gary L. Bradshaw
glb2@ra.msstate.edu

Professor of Psychology and
Director of Applied Cognitive Science Ph.D. Program

Mississippi State University
Mississippi State, MS 39762

Abstract

The past decade has witnessed the widespread perfusion of the world-wide web throughout western culture. Ten years ago it was rare for an office, library, school, or home to have computers available for web browsing. Now the reverse is true. This vast expansion of the web has permitted various kinds of online learning systems to appear in such abundance that it is difficult to keep track of them all. Yet college students still usually buy and read printed textbooks (perhaps with a CD-ROM or associated web site) and significant obstacles remain for widespread adoption of electronic textbooks instead of printed textbooks. Against the backdrop of human learning, this article will explore the advantages and disadvantages of electronic multimedia textbooks vis-à-vis traditional textbooks. Some interesting solutions to the effective employment of multimedia texts are drawn from ePsych, a free and open website designed to introduce student visitors to psychology. ePsych, a 2005 recipient of the MERLOT Classics award in Psychology, is a moderate-sized website of approximately 2,800 html pages, 410 video clips, 61 java-based experiments and simulations, and 5,200 image files.

Multimedia Textbooks and Student Learning

The goals of this paper are threefold: First, we review some important principles of human learning that can inform the development of learning objects in general and electronic texts in particular; Second, we compare web-based textbooks with their traditional paper versions, illustrating some of the competitive advantages and disadvantages of electronic texts; Third, we illustrate how these advantages and disadvantages have been addressed in *ePsych* (Bradshaw, McCarley, & Steinman, 2002), an online multimedia textbook that introduces the discipline of psychology to visitors. ePsych is a free and open website sponsored by the National Science Foundation.

Key Principles of Learning

Although the psychology of human learning is an active and incomplete field, much has been learned about how learning takes place and conditions that foster learning. The topic is too large and complex for a full treatment here. Instead we highlight important principles for learning declarative material (facts, theories, or concepts) from a paper or electronic textbook. These findings can inform efforts to develop electronic texts or other learning objects/systems, but are less applicable to skill-based learning needed to master fields like mathematics or statistics.

Basics of Learning

New concepts, facts, theories, or relationships are stored in a person's long-term memory. To be successfully encoded as a long-term memory and later retrieved, three factors appear to be critical at elementary levels of learning: "concreteness," "connectedness," and practice. Concreteness refers to a grounding in direct sensory experience, in contrast to an abstract character. Novice reasoning tends to be circumscribed by the physical world of experience, whereas experts reason using general and abstract principles (Chi, Feltovich, & Glaser, 1981). Connectedness refers to how integrated a piece of knowledge is, both to previously learned knowledge and to other new information. Acquiring an isolated fact is of little value to a learner, and the isolation all-but-guarantees difficulty in remembering the item, whereas facts that relate to one another and to past experience have a better chance of recall. Practice is perhaps the most widely appreciated element in learning, reflected in the familiar idiom "Practice makes perfect." We will review each of these principles in turn.

Learning From Concrete Experience

The expert-novice literature contains a wealth of studies documenting a simple fact: Novice reasoning employs concrete principles grounded in sensory experience whereas expert reasoning is free to follow more abstract paths. Chi, Feltovich, and Glaser (1981) asked subjects to classify a large set of problems into similar categories. Novices sorted the problems using superficial characteristics, such as the presence of inclined planes, as the basis of their classification. Experts sorted the problems very differently. They classified problems based on deeper principles that are more predictive of the method of solution (Anderson, 1995).

This difference is not simply a difference in knowledge – instead it reflects a fundamental constraint on learning. Doane, McNamara, Kintsch, Polson, Clawson, and Dungca (1992) showed that novice performance did not improve when learners were supplied with abstract information sufficient to carry out the task. Instead, improvement only followed upon the presentation of concrete information.

Thus a natural conflict arises between an educator's goal of *teaching an abstract version* of the material that can be applied broadly and a student's *desire for a concrete version* that is easy to understand but will have limited generality. The solution is normally to use a concrete example to illustrate an abstract principle. Later we will show that multimedia electronic texts have a distinct advantage over printed books in providing certain types of concrete examples.

Learning a Network of Connected Material.

Learning is not so much a matter of *mastering isolated facts* as *assimilating a body of knowledge*. Assimilation is strongly influenced by the "connectedness" or coherence of the knowledge. Bradshaw and Anderson (1982) demonstrated the utility of internal connectedness in an experiment in which subjects learned some little-known information about famous people. Subjects learned either one or three facts about each famous person. If a subject learned three facts, they were either related to one another or were unrelated. Table 1 illustrates the stimuli used in the experiment.

Table 1: Stimuli (From Bradshaw and Anderson (1982))

Single-fact condition
Mozart made a long journey from Munich to Paris.

Related fact condition
Mozart made a long journey from Munich to Paris.
Mozart wanted to leave Munich to avoid a romantic entanglement.
Mozart was intrigued by musical developments coming out of Paris.

Unrelated-fact condition
Mozart made a long journey from Munich to Paris.
Mozart wrote an important composition when he was 14 years old.
Mozart's father was critical of his marriage.

Here recall was best for the related-fact condition and worst for the unrelated-fact condition. The related facts permit *inferential redundancy.* Inferential redundancy is beneficial when a learner has difficulty in direct retrieval. Assume a student could not remember that Mozart made a long journey from Munich to Paris, but did remember that Mozart wanted to leave Munich and was intrigued by musical developments coming out of Paris. This information allows the student to infer the missing knowledge.

Inferential redundancy is not helpful in the unrelated-fact condition. Recall was lowest when subjects were asked to learn three isolated facts, illustrating the principle that isolated facts are difficult to remember.

Facts in the related condition were connected through causes and effects. Of course, facts are not always related to one another in this manner, but learners must recognize and understand how the facts link with one another or the material can appear to be a series of unrelated facts. Bransford and Johnson (1972) performed an important experiment illustrating this point. Upon reading a passage from their experiment as it appears in Table 2, most people find it difficult to interpret.

Table 2: Passage from Bransford and Johnson (1972)

The procedure is actually quite simple. First you arrange things into different groups depending on their makeup. Of course, one pile may be sufficient depending on how much there is to do. If you have to go somewhere else due to lack of facilities that is the next step, otherwise you are pretty well set. It is important not to overdo any particular endeavor. That is, it is better to do too few things at once than too many. In the short run this may not seem important, but complications from doing too many can easily arise. A mistake can be expensive as well. The manipulation of the appropriate mechanisms should be self-explanatory, and we need not dwell on it here. At first the whole procedure will seem complicated. Soon, however, it will become just another facet of life. It is difficult to foresee any end to the necessity for this task in the immediate future, but then one never can tell.

The difficulty in following this passage does not derive from the complexity of the constituent sentences, which independently are easy to read and understand. Instead the difficulty arises in connecting the different sentences together. Subjects who were informed ahead of time that “The paragraph you will hear will be about washing clothes” had a much-higher recall rate than subjects who did not receive this clue to the paragraph topic. But subjects who learned the topic *after* hearing the passage still had considerable difficulty recalling it.

Texts normally require *bridging inferences* to connect the material together (Kintsch, 1998). These bridging inferences may be simple and obvious as in the sentences: “The boy teased the dog. It barked.” Note that the pronoun ‘it’ requires us to identify the thing ‘it’ is substituting for. Clearly the *dog* barked and not the boy. This bridging inference can be made by young readers and would pose no difficulty for college students. But in the Bransford and Johnson passage, the first sentence refers to ‘groups’ of things while the second refers to ‘piles.’ Without knowing the topic of the paragraph, it is unclear whether the groups and piles are the same thing. Indeed the paragraph deliberately violates several *maxims of conversation* (Grice, 1975) that a writer or speaker would normally follow to reduce the complexity of bridging inferences needed by a reader or listener. Knowing the topic of the paragraph, our background knowledge can help fill in the unstated and create bridging inferences that permit coherent interpretation.

Someone who is unfamiliar with washing clothes and Laundromats would not be helped much by hearing the topic of the paragraph. Thus if we were teaching about polymer synthesis or quantum mechanics, students may well find themselves in precisely that situation: they do not have the background material that will allow them to make needed bridging inferences. Without being able to make bridging inferences, the text is incoherent and students cannot extract its meaning. Without being able to understand the meaning of the text, they cannot add to their body of background information that might provide bridging inferences. Learning under these conditions is effortful at best and impossible at other times.

Although students may simply be given material in which the relationships are obvious and explicit, they can also generate helpful elaborations on their own. Active learning encourages students to construct their own bridging inferences, resulting in a redundant, interconnected network. Many study techniques encourage students to form questions about the material they are learning (e.g., the SQ3R method; Robinson, 1961; the PQ4R method; Thomas & Robinson, 1972). Forcing oneself to ask questions facilitates the construction of inferences and elaborations (Anderson, 2000). Once again, electronic texts have the potential for a significant advantage over printed texts.

Learning and Practice.

Practice is the final important component of this basic analysis of learning: Practice strengthens memory traces. But immediate practice is of little or no value (e.g., Glenberg, Smith, & Green, 1977), whereas practice at a delay is of greater benefit (e.g., Nelson, 1977). Similarly, rote rehearsal is a particularly unhelpful form of practice. Students who employ this approach toward learning often perform more poorly than students who employ elaboration as they study (e.g., Anderson & Bower, 1972; Brown, 1979).

Although immediate practice is not helpful, too long a delay before practice may also have negative effects: If a student cannot retrieve the material from memory and has to go back and re-learn the material, additional effort may be required when compared to practice at a moderate delay. Students may become discouraged at the effort and neglect additional practice.

Testing a student on his or her knowledge may be one of the best ways to practice. Not only does the student get an opportunity to rehearse the material, the question may force the student to elaborate upon what he or she has learned.

Multimedia electronic and printed texts

As the web has grown and become more prevalent, investigators have conducted any number of comparisons between electronic and traditional texts. Again, a full review of the research falls well beyond our scope, and again I will present some highlights of the research along with some original observations.

Books and computer screens differ in many ways. A printed page typically has a much higher resolution than most computer screens, so that publishers can show more material at a time than can electronic texts. Books also require no power supply or network connection, and can be used at Laundromats, football games, or riding the bus to class. Students frequently use a highlighter to mark selected passages for quick review later on. Books also have a long shelf life and the economics of print-based publication are well established. Electronic texts require a computer for display and seldom support highlighting. Online versions of electronic texts further require network access. It is usually not possible to "thumb through" an electronic chapter, and download times may be lengthy over a modem. The availability of many different generations of browsers of various types on various operating systems can lead to compatibility problems for all but the most generic texts. Finally, the world-wide web offers a tremendous amount of free material, and people are not accustomed to paying for computer-based material. Developers have no obvious revenue sources to support the development and distribution of new electronic texts.

Although these factors have slowed the progress of electronic texts, there are deeper factors at work that will likely more than compensate for these disadvantages. In particular, computer-based learning systems can utilize the computational power of the host machine, feature dynamic displays that can display multimedia elements, and are governed by very different economics than textbooks. The first two points need little elaboration, but the third demands further explanation.

Textbook publishers are concerned with two different costs: the cost of producing the first copy of a textbook and the cost of reproducing that copy. Production costs include payments to authors, editors, artists, and typesetters. The cost of reproduction depends on the length of the book and the number of colors of ink on each page: The greater the number of pages and the greater the number of illustrations, the more expensive each copy of the book will be to make. These factors put pressure on publishers and authors to be brief, concise, and to employ a minimum of illustrations.

In computer-based publication the economics of reproduction are quite different. Copying involves shipping bytes from one computer to another. Today's networks are so efficient that hundreds of pages of text can be sent in a few minutes' time: The complete text in this article could be downloaded in about one second over a 28.8 KB/sec modem. Although still images and movies take longer, the cost of sending and receiving information is negligible and is not billed directly, in contrast to long-distance telephone charges like "7 cents/minute" or electric costs in kilowatts/hour.

Collectively the computational power, dynamic displays, and low reproduction costs of electronic texts offer some significant potential advantages over their paper-based cousins. We will consider how each of these factors plays a role in promoting learning from concrete experience, mastering complex networks of material, and strengthening memories through practice. Each of these principles will be illustrated with material from ePsych (http://epsych.msstate.edu), a web-based introduction to Psychology.

Learning from Concrete Experience.

Here two limitations of printed texts will loom large: the fixed quality of the printed page and the high cost of textbook reproduction. These limitations have somewhat different consequences, so we discuss each in turn.

The fixed character of a printed page precludes a textbook from directly illustrating change: It is not possible to show something that changes over time; instead the change can only be described. Students, who benefit from concrete experience, are forced into decoding an abstract description instead. Consider the Figures 1, 2, and 3 that depict for McClelland and Rumelhart's (1981) Interactive Activation model.

To understand the model, students must understand that each of the two graphs is depicting the change in activation level over time of nodes in the network. The interactive activation phenomenon arises through the interplay of nodes at various levels, so the student must relate the two graphical functions to one another using the architectural diagram (showing the facilitative links and inhibitory links) driven by complex nonlinear equations. Notice how divorced all of this is from concrete experience. But computers can *simulate* the model, allow students to interact with it and appreciate the delicate flow of activation and inhibition throughout the network. This provides a concrete basis of experience to support learning.[i]

ePsych does not include this particular simulation, but it does offer a similar simulation known as Pandemonium. The Pandemonium model (Selfridge and Neisser, 1960) uses demons to detect visual features and identify letters. By interacting with this model students can appreciate how it is able to identify letters even when features are missing or incorrect. But they can also learn this approach has drawbacks as well: Pandemonium will 'recognize' a letter even if a single bit of the letter is present, such as the tail of a Q. Other simulations on ePsych include a simulation of operant conditioning, where a fuzzy alien creature can be taught certain behaviors, and a unit on neural networks that can be trained to perform simple tasks.

Beyond the ability of electronic texts to incorporate dynamic simulations and video clips of time-based phenomenon, such texts also enjoy an advantage because of low reproduction costs when compared to printed texts. Textbook authors are under considerable pressure to employ a succinct and minimalist style, simply to help hold down the ultimate cost of the resulting textbook. Electronic texts do not suffer from the same economics, so authors can present the material at a more measured pace. This means that multiple examples can be provided, or even multiple simulations of the same phenomenon. ePsych has a unit on neural networks. This unit includes 7 distinct java-based neural network simulations. These begin with very simple simulations. Students learn how to control a simulation where only a few changes can be made, then learn to master increasingly sophisticated simulations with more possible controls. This style of presentation is all-but-prohibited by the cost of reproducing the printed page. But it fits well with a learner's needs to work from concrete examples as they seek to master abstract principles.

Learning a Connected Network of Material.

Once again I will argue that printed textbooks are at a disadvantage in helping students build a connected network of material when compared against electronic texts. Again the disadvantage stems from the different economics of reproduction: The expense of each printed page pressures

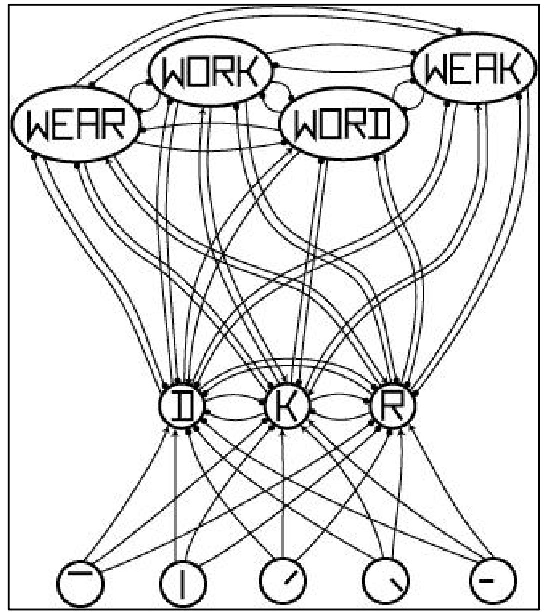

Figure 1. Interactive Activation Network Model (after McClelland and Rumelhart, 1981).

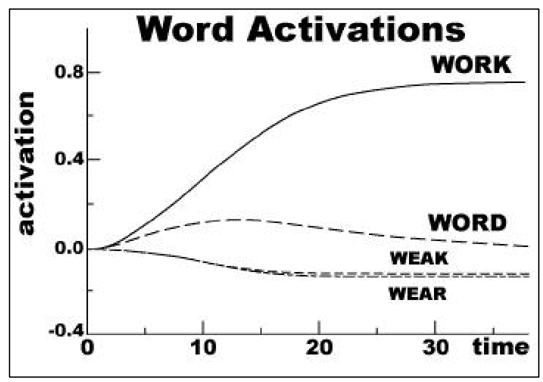

Figure 2. Activation functions for words over time in the Interactive Activation Model.

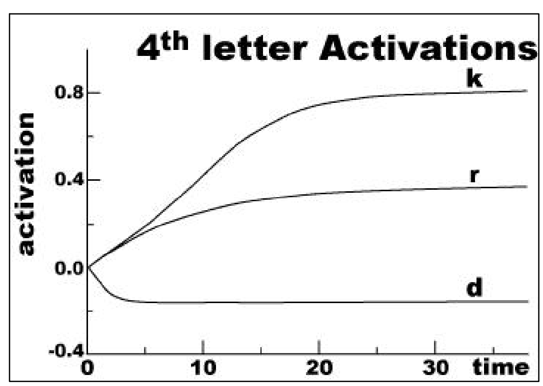

Figure 3. Activation functions for letters over time in the Interactive Activation Model.

authors and publishers to present the material in a terse style. But this style is not needed in electronic texts, where the costs of reproduction are negligible.

Simply put, electronic texts may employ a careful and complete style of communication that textbook publishers simply cannot afford to employ. By providing more of the background material explicitly, readers escape the need for difficult bridging inferences. More examples can be provided to illustrate points. Authors can also tie in their material to a student's personal experience. This does not, of course, mean that longer is always better: At some point the added material is not worth the extra time on the part of the reader. However, contemporary textbooks almost invariably employ a terse and Spartan style that places unnecessary burdens on students.

There are other ways where the readability of material can be improved in electronic texts. In ePsych's module on the neuron, for example, a common illustration of the neuron is printed in five different forms, each with two unique labels per appearance. Each illustration appears on a distinct web page that discusses the two labeled items. A textbook illustration has all 10 labels, forcing students to search around a busy diagram to find each structure identified in the text.

Hypertext offers an additional capability for non-linear writing that can provide support only when it is needed. One method that is occasionally employed in ePsych is the availability of a popup dictionary that provides the definition for a term. Clearly more could be done along these lines, but these features must be designed with care: Students can easily get lost wandering around a hypertext maze and never make any real progress on any given topic (Dillon, 2004). Converting material to hypertext led to a decrease in comprehension and an increase in usage time for computer documentation (Hunter-Krauss, Middendorf, & Willits, 1991), although in other applications, researchers have found an advantage for hypertext over printed documents (Leventhal, Teasley, Instone, Rohlman, & Farhat, 1993).

Practice and Learning

The previous two sections demonstrated a clear advantage that electronic textbooks enjoy over traditional printed versions. The difference between electronic and traditional texts is not as great in the area of practice, though again electronic textbooks have a potential advantage.

One vehicle for practice is to 'quiz' students at a short delay. ePsych features JavaScript based skill exercises that serve this purpose. Students are asked to complete a short series of questions on the material they have just learned. If students do not select the correct answer on the first trial, they have an opportunity to select another answer. Of course, students can eventually work their way through each skill exercise just by trial-and-error. However, if students can make a reasonable guess as to the correct answer, they will complete the exercise faster. The questions often employ different language or examples, providing a different context that encourages elaboration during rehearsal. At the end of each skill exercise, students see how many of the answers they got correct on their first pick. This information can help student monitor their progress and to review the material if necessary before going on.

Textbooks can have these sorts of review questions in the book, though they are rare in introductory Psychology texts. These are roughly equivalent in practice to the skill exercises on ePsych. However, there are some small advantages of the ePsych version over a printed text. One advantage arises because textbooks are often sold from one student to the next, so any markings that are made on the questions will allow the succeeding owners to avoid answering the questions on their own. Scoring the results may necessitate looking somewhere in the back of the book, an inconvenience the increases the apparent effort of the quiz. But these are modest disadvantages, not telling ones.

Commercial online systems, like Blackboard and WebCT, allow teachers to construct and distribute formal quizzes and tests to students via the web. This route was not followed in ePsych for three reasons. First is the issue of authentication: establishing the true identity of the user taking the test. There are various means to authenticate user identity but few offer any real protection against a skilled cheater. Next, the number of items that can be generated in this field is small so that organizations like fraternities can establish a 'quiz bank' with the correct answers identified. But perhaps most importantly we did not want students to view our skill exercises as a test but rather as a learning tool. If the scores are collected and reported, students might mistake them for an examination and be encouraged to find ways to inflate their scores. Hopefully students will view our skill exercises as a way to monitor their understanding and to practice their newfound knowledge.

Conclusions

Printed textbooks have a long history in education and still retain several important advantages over electronic texts. Yet electronic texts also have their unique strengths in meeting the needs of learners: Electronic texts can incorporate simulations and other concrete examples, employ a style well-suited to a learner's needs, and work in the opportunity to practice and elaborate upon what students have learned. In the long run, these advantages will likely result in increasing adoption of electronic textbooks, especially at a beginning level where students are struggling to master the basics of a field. As students learn the basic concepts in a concrete form they will likely be able to learn effectively at a more abstract level, and certainly need to do so. Thus, for more advanced learners paper texts may retain their superiority over electronic texts for a considerable period of time.

Acknowledgements

Many individuals have contributed to the development of ePsych over the past several years. Prof. Mike Thorne has scripted several ePsych modules in the recent past. Chris Nolen produced much of the ePsych artwork, with Clayton Graff and Zach Prichard contributing much of the 3-D work. Connie Harris brought many of the elements together with her superb HTML work. Don Goodman wrote several of the simulations and java demonstrations. Prof. Nancy McCarley assisted in evaluations of ePsych. Additional contributors include Bernard Steinman, Jennifer Daniels, and Tony Hocevar. ePsych is richer for all the fine work performed by these great people! ePsych development has been supported by grants DUE-9981004 and DUE-0089420 from the Division of Undergraduate Education at the National Science Foundation. Special thanks are due to our NSF program officer Myles Boylan for his consistent support of this work. The kind suggestions of two JOLT reviewers, which led to improvements in this article, are gratefully acknowledged.

---

[i] A java-based interactive activation model is located at http://www.psychology.nottingham.ac.uk/staff/wvh/jiam/ . ePsych does not have this model, although ePsych does have related simulations available for *Pandemonium* (http://epsych.msstate.edu/descriptive/swamp/Pandemonium) and neural networks (http://epsych.msstate.edu/biological/NeuralNetworks).

References

Anderson, J.R. (1995). *Cognitive Psychology and its Implications 4th Ed.* New York: W.H. Freeman & Co.

Anderson, J. R. (2000). *Learning and Memory an Integrated Approach 2nd Ed.* New York: John Wiley & Sons

Anderson, J.R. & Bower, G.H. (1972). Configural properties in sentence memory. *Journal of Verbal Learning and Verbal Behavior, 11,* 595-605.

Bradshaw, G.L., & Anderson, J. R. (1982). Encoding elaboration as an explanation of levels of processing. *Journal of Verbal Learning and Verbal Behavior, 21,* 165-174.

Bradshaw, G.L., McCarley, N., & Steinman, B. (2002). ePsych: Interactive demonstrations and experiments in psychology. Behavioral Research Methods, Instruments and Computers, 34, 231-233.

Bransford, J.D., & Johnson, M.K. (1972). Contextual prerequisites for understanding: Some investigations of comprehension and recall. *Journal of Verbal Learning and Verbal Behavior, 11,* 717-726.

Brown, A.L. (1979). Theories of memory and the problems of development: Activity, growth, and knowledge. In L.S. Cermak & F.I.M. Craik (Eds.), *Levels of Processing in Human Memory.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Chi, M.T.H., Feltovich, P.J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5,* 121-152.

Dillon, A. (2004). Designing Usable Electronic Text 2nd Edition. Boca Raton, FL: CRC Press.

Doane, S. M., McNamara, D. S., Kintsch, W., Polson, P. G., Clawson, D.M., & Dungca, R. G., (1992). Prompt Comprehension in UNIX Command Production. *Memory and Cognition*, *20*, 327-343.

Glenberg, A.M., Smith, S.M., & Green, C. (1977). Type I rehearsal: Maintenance and more. *Journal of Verbal Learning and Verbal Behavior, 16,* 339-352.

Grice, H. P. (1975). Logic and conversation. In P. Cole (ed.) Syntax and Semantics. Vol. 3. New York: Academic Press. 41-58.

Hunter Krauss, F.S., Middendorf, K.A. and Willits, L.S. (1991). A Comparative Investigation of Hardcopy vs. Online Documentation. *Proceedings of the Human Factors Society 35th Annual Meeting v.1* , p.350-353

Kintsch, W. (1998). Comprehension: A paradigm for cognition. Cambridge: Cambridge University Press.

Leventhal, L. M., Teasley, B. M., Instone, K., Rohlman, D.S., Farhat, J. (1993). Sleuthing in HyperHolmes: An Evaluation of Using Hypertext vs. a Book to Answer Questions. Behaviour and Information Technology, 12, 149-164

McClelland, J. L., & & Rumelhart, D. E. (1981). An interactive model of context effects in letter perception: I. An account of basic findings. *Psychological Review, 88,* 375-407.

Nelson, T.O. (1977). Repetition and depth of processing. *Journal of Verbal Learning and Verbal Behavior, 16,* 151-171.

Selfridge, O., & Neisser, U. (1960). Pattern recognition by machine. *Scientific American, 203:* 60-68.

Robinson, F.P. (1961). *Effective study.* New York: Harper & Row.

Thomas, E.L., & Robinson, H.A. (1972). *Improving reading in every class: A sourcebook for teachers.* Boston: Allyn & Bacon.