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ABSTRACT

Maps or graphical browsers of structural knowledge allow the user of a hypertext system to navigate from node to node through the structure as they portray the links between concepts spatially. This study examined the results of using two different graphical browsers that provide different amounts of information about the structure of the knowledge. The use of graphical browsers was compared with that of hotwords embedded in the instructional text itself but having no explicit structure. Subjects were 113 undergraduates for whom verbal Scholastic Aptitude Test scores served as a measure of verbal ability. Treatment effect was assessed through posttests, and student paths were recorded for each treatment. It was not evident from the results that all learners internalized the structural knowledge provided by the graphical browsers. Those with high prior knowledge showed a greater increase in structural knowledge. Use of hotwords resulted in lower achievement, and verbal ability was not a factor on most variables. Users of hypertext appear to require extended experience to become comfortable and proficient. Twelve tables present study findings. (Contains 68 references.) (SLD)

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Title:

Navigating through Hypertext: Navigational Technique, Individual Differences, and Learning

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Background

Information presented in instruction consists of declarative and procedural knowledge as well as structural knowledge -- the way declarative knowledge concepts are interrelated (Jonassen, 1990). Individuals selectively incorporate this new information into their existing cognitive structures and then utilize the information in these frameworks when applying the knowledge to new situations. Knowledge of content structure portrayed in instructional materials can help the learner in two ways: 1) by organizing information in short-term memory to build internal connections among the new information and 2) by integrating this information with existing knowledge structures in long-term memory to develop internal connections (Mayer, 1984).

Strategies. In designing instruction, generally an expert's conception of the structure of the knowledge is mapped onto the instructional materials, either implicitly in the text structure and text elaboration techniques or explicitly through graphic portrayals of the text structure. Beissner and her colleagues (1993) list types of implicit strategies: signalling (Meyer, 1975), frames and slots (Armbruster & Anderson, 1985), and elaboration theory (Reigeluth & Stein, 1983). Explicit strategies that graphically portray the structure of knowledge for the learner or ask the learner to construct such a representation include semantic mapping, semantic features analysis, structured overviews, graphic organizers, spider maps, pattern notes, concept maps, networking, text mapping, schematizing, advance organizers, and insertions such as pictures, questions, and verbal elaboration (Beissner, Jonassen, & Grabowski, 1993; Gagne, 1986).

Mapping structural knowledge onto instructional materials is thought to help learners assimilate the new information into their cognitive structures -- adding to existing schema, modifying them, or creating new ones as necessary. Studies have shown that a student's cognitive structure grows more similar to that of the instructor or the instructional materials studied (Shavelson, 1974; Thro, 1978; Naveh-Benjamin, McKeachie & Lin, 1989).

Hypermedia. Many of these techniques assume the learner is using a linear form of instruction, similar to a textbook. The learner is led through a prescribed path and exposed to the information in a structured fashion reflecting the expert's model. Some of the newer technologies, such as hypertext or hypermedia, offer the ability to give the learner control over his/her path through the instructional materials, hopefully discovering the structure of the knowledge in the process. Each individual can take a different path, encountering different amounts and types of information in different sequences. Hypermedia offers both potentials and problems in conveying structural knowledge and assisting learners in incorporating this structural knowledge into their own personal frameworks. Such non-linear systems offer the ability to present various complex structural representations in a domain, to show different points of view, to show diversity among similar examples, and to show similarities across different categories (Spiro and Jehng, 1990). They can allow the learner to explore alternatives and discover relationships (Heller, 1990). As the learner maps out a path through the material, he/she must make choices and become a more active learner (Bourne, 1990).

At the same time, such systems can cause disorientation in the learner, overtax cognitive processing capabilities, encourage over-simplification, over-generalizations, and over-compartmentalization (Conklin, 1987; Hammond; 1989; Jones, 1987; Spiro and Jehng, 1990). The learner is required to absorb layers of information, make it personally meaningful, and gain a comprehensive picture of the subject (Bourne, 1990).

Hypermedia's organization of nodes and links perpetuates the designer's assumptions about the nature of knowledge (Doland, 1989), but this structure is not as explicit as in traditional print materials (Charney, 1987). Some question whether this semantic network reflected in hypertext can be transferred to learners or whether hypertext's network is analogous to the mind's semantic network (Duffy & Knuth, 1990; Romiszowski, 1990; Whally, 1990; Landow, 1990).

One of the challenges for instructional designers and learners is how to represent the information and connections for learning and information retrieval. Research on text structure and comprehension, schema development, metacognition and self-regulation, learner control, and text enhancement techniques provide a basis for designing instruction to improve acquisition of structural knowledge. Most of this research has dealt with linear, text-based instruction. The current study examined some of these findings in light of a non-linear computerized database that allows the individual learner control over his/her own learning. Horn (1989) describes human memory as associative, sometimes connecting information in unpredictable, idiosyncratic ways and other times in hierarchical, structured ways. Jonassen (1991) proposes that the node-link structure of hypertext reflects the semantic structure of the expert's knowledge. Semantic maps of an expert's or experts' structure of a subject could be used to create a node and link structure in hypertext.

Individual Differences. Research has shown that degree of prior knowledge, i.e., existing schemata, influences learning, reading, and inferencing (Clark, 1990; Anderson & Pearson, 1984; Roller, 1990; Gay, 1986; Fincher-Kiefer, 1992; Spilich, Vesonder, Chiesi & Voss, 1979; Chiesi, Spilich & Voss, 1979). Users may have difficulty tracking the overall structure of information in a hypertext system and relating it to their prior knowledge. This problem may be exacerbated for students with low prior knowledge by causing disorientation and cognitive overload.

Verbal ability differences may also influence a student's ability to process new information in a hypertext system, particularly since students with low verbal ability may be inefficient in semantic, syntactical, and pragmatic processing of linguistic information (Hunt, 1983). Landow (1989) claims that some of the new technologies change the way readers read because determining relationships among the linked concepts, which may not be obvious to the user, becomes central to understanding. This requires a new type of understanding, especially difficult for poorer readers who tend to strictly follow a text's linear presentation and seldom use traditional connective aids such as glossaries and introductions in print materials. They are not used to having to create associations among concepts on their own.

Graphical Browsers. New skills and instructional aids may be required to use these technologies. Explicit techniques different from those in traditional text can help the learners perceive the structure of the knowledge. Spatial learning strategies provide a way of graphically portraying structural knowledge for the learner or asking the learner to construct such a representation. Breuker (1984) sees them as providing external memory storage and explicitly depicting concept interrelationships. They focus attention on relevant information and help the learner create internal and external connections among the concepts.

Maps or graphical browsers of the structural knowledge allow the user of a hypertext system to navigate from node to node through the structure while spatially portraying the links between concepts (Halasz, 1988). They generally allow the user to directly access any node on the map, speed up information access, and prevent disorientation (Tsai, 1989). "The learner can use a semantic network as a map of the content knowledge in a curriculum and use this map to explore topics that are of interest to him or her at the time the interest is present" (Denenberg, 1988, p. 309). Denenberg recommends showing only the structure around one node to avoid overwhelming the learner. This avoids some of the problems of global maps (Conklin, 1987).

These graphical browsers are thought to influence information processing by facilitating both the organization and integration of new information, similar to the way signalling techniques such as typographic cues and the placement of certain words highlight the text structure (Spyriakis, 1989). Graphical browsers draw the learner's attention to the important concepts and how they are related to each other. They can help the learner tie the new information to prior knowledge in long term memory, especially when some terms in the graphical browser are already familiar to the learner. This tie to already known schema may be most useful for learners with high prior knowledge who recognize some concepts and can use the browser to help decide where to go next. They benefit most from this learner control.

Graphical browsers can also help the learner organize the new information in short term memory by setting up a framework to facilitate encoding. This may be more useful for those with low prior knowledge who have little existing framework for the new information but could potentially interfere with encoding by those with high prior knowledge who already have a well-established framework. A system without such graphical browsers would force the learner to generate his/her own framework, creating a more active learner. The effectiveness of this navigation technique may be tied to the degree of prior knowledge, both of facts and of the relationships between them, i.e., the learner's existing cognitive framework.

Jonassen and Wang (1990, 1992, 1993) and Jonassen (1991) have conducted several studies on the use of several types of graphical browsers in hypertext systems to acquire structural knowledge. They found no significant increase in structural knowledge and, in some cases, an actual decrease in recall. Only those specifically told they would be required to create a semantic network after the task showed significantly increased structural knowledge. They concluded that merely showing the structural relationships was not sufficient to result in encoding. In their studies they used measurement techniques that attempted to assess higher level skills and transfer, often achieving a basement effect in the scores. Learners were unfamiliar with these testing techniques and were unable to complete them. Also, these studies used a very large database, raising the question of how much information each learner actually covered.

Phillips and his colleagues (1992) examined different types of navigational devices in a hypertext database and found that those provided with the most minimal navigational tools (i.e., hotwords in the text itself) achieved the highest recall. This study investigated only recall of facts and concepts, but combined with the Jonassen and Wang studies, it raises the question of how much explicit structure is optimal for facilitating information processing by learners. The current study examined both higher level structural knowledge and declarative knowledge, measured retention over time, measured structural knowledge using an assessment technique more understandable to the learners, and compared learners with different degrees of prior knowledge in the content area and different degrees of verbal ability to determine the optimal degree of explicit structure for different learners.

The study examined the results of using two different graphical browsers providing different amounts of information about the structure of the knowledge to learners who have been given a specific, externally imposed objective and a structural knowledge task at the beginning of instruction. This was compared to the use of hotwords embedded in the instructional text itself showing no explicit structure. These pre-lesson strategies of providing objectives and a structural knowledge task were intended to alert the learners to the importance of acquiring structural knowledge and to provide a purpose for their browsing. Given that Jonassen and Wang (1990) found many participants were unfamiliar with structural knowledge acquisition and integration, hypertext techniques, and methods of assessing structural knowledge, the study also provided practice in basic hypertext navigation to reduce anxiety and to develop appropriate strategies for navigation and integration and familiarity with a graphical browser before the instruction.

Several authors (Whalley, 1990; Duchastel, 1990; Spiro and Jehng, 1990) have suggested that hypertext may not be appropriate for many instructional uses. Whalley suggests that browsing is the most appropriate use of hypertext. Browsing may not be most appropriate for instructional purposes, but it may be appropriate for facilitating discovery learning (Bruner, 1960). Duchastel (1990) and Spiro and Jehng (1990) suggest that hypertext is inappropriate for highly structured learning tasks. There is little empirical research to support these claims. This study examined some of these criticisms of hypertext by using it for just such a highly structured content domain that includes facts, concepts, and principles.

Research Questions

These questions about the educational use of hypertext led to the following research questions.

1. Will students given no explicit graphical representation of relationships among concepts (Hotwords group), those given a graphic method for showing the relationships (Links group), and those given a graphic method for showing relationships with the relationships labeled (Detailed Links groups) have different levels of structural knowledge and perform differently on tests of comprehension and recall of facts and concepts?

2. Is there an interaction between degree of *prior knowledge* and type of graphical method for showing structural knowledge on the learner's immediate and delayed structural knowledge, comprehension, and recall of facts and concepts?

3. Will the graphical method for representing structural knowledge during instruction bring the learners' *structural knowledge representations closer to that portrayed in the instructional materials*?

4. Will the type of graphical method for representing structural knowledge affect the retention of facts, concepts, and structural knowledge *over time*?

5. Is there an interaction between degree of *verbal ability* and type of graphical method for demonstrating structural knowledge on the learner's immediate and delayed structural knowledge, comprehension, and recall of facts and concepts?

This study examined the use of three types of navigational techniques representing structural knowledge in a hypertext system for their influence on the acquisition of declarative and structural knowledge. The effects of prior knowledge, verbal ability, amount of the content seen, and time spent using the system on achievement were examined. In addition, the change in a student's structural knowledge and its similarity to an expert model were assessed. Finally, retention over time was assessed using the same measures.

Methods

Subjects

One hundred-thirteen undergraduate volunteers from a large state university received extra credit for participating in both sessions of the study. One-hundred forty-started the study, but five did not have SAT scores, ten did not return for the second session, and twelve did not complete the first session. These subjects were dropped.

Treatments

Subjects were randomly assigned to a system using hotwords, one using a graphical browser representing the links between concepts, or one using a graphical browser labeling the relationships between concepts.

A sixty-screen hypertext database on the parts of the heart, circulation, and blood pressure based on the materials of Dwyer and Lamberski (1977) was developed for this study. This content was selected because it covers a variety of facts, concepts, and processes and represents a limited subject domain on which there is general consensus on the organization of the content. An overarching structure for the system with each screen represented as a node was created. Graphical browsers and hotwords representing all nodes linked to each screen were created for the different treatments. Links were hierarchical, heterarchical, and following the flow of blood through the heart.

Each treatment had the same screens with only the structural knowledge representation methods differing. The treatments were:

1. A group which highlighted the terms to be linked that, when clicked, took the learner to a related screen without describing how the two screens are related (HOTWORDS).
2. A graphical browser with links visible but not described but otherwise the same as the third treatment (LINKS), and
3. A graphical browser with links described along the lines (DETAILED LINKS).

The learner could go to each link in succession from hotspots on the screen. By clicking on all the hot buttons, the learner could access the same screens in all three treatments. The students were allowed to work through the program at their own pace, accessing whatever screens they saw fit. They could exit the program at any time.

Instruments

The students were randomly assigned to the three treatment groups, based on the assumption that prior knowledge and verbal ability scores would be equally distributed among the groups.

The following measurements were taken for each subject:

1) a pretest of prior physiological knowledge,
2) a pretreatment assessment of structural knowledge,
3) verbal Scholastic Aptitude Test score,
4) a posttreatment survey of previous computer use and attitudes toward computers, hypertext, and this program,
5) the number of different screens each subject chose to view, and
6) the amount of time spent on the treatment.
7) a 40-question immediate criterion posttest measuring recall of facts and concepts and comprehension consisting of three multiple-choice tests and one drawing test used to assess recall and comprehension developed by Dwyer (1978) (Test),
8) an alternate form of the 40-question criterion posttest administered approximately two weeks after the immediate posttest (Retest), and
9) a post-treatment assessment of structural knowledge (Tree2)

From the Test and Retest scores, a change score was calculated for the posttests. From the third, the ordered-tree technique, a similarity measure to an "expert" structural knowledge representation and a change in structural knowledge were calculated.

The ordered-tree technique has been used in numerous studies to assess a learner's cognitive structure (NavehBenjamin and others, 1986; McKeithen and others, 1981; Naveh-Benjamin, McKeachie, and Lin, 1987; NavehBenjamin, McKeachie, and Lin, 1989) and is based on a theory of hierarchical cognitive structure that assumes concepts are organized hierarchically with single concepts at the lowest level and more abstract categories at the higher levels. The technique uses recall theory which describes individuals' tendency to list all of one branch of the hierarchy before moving on to the next branch. From a number of cued and uncued trials, where subjects put sets of low-level concepts in order, an algorithm finds the set of all chunks for each subject and creates representations of the subjects' cognitive structures (Naveh-Benjamin & Lin, 1991). It measures amount of organization, depth of the hierarchy, similarity to an "expert" organization, and direction of relationships between concepts.

The method was validated by two content experts and checked for reliability through a field test. This technique was used to assess structual knowledge both before and again two weeks after the treatment in this study to examine a subject's prior structural knowledge and then the change after the treatment. The pretreatment and posttreatment structural knowledge tasks in this study were scored using the scoring system for the structural knowledge assessment technique developed by Dr. Henry Rueter of the Cognitive Science and Machine Intelligence Laboratory at the University of Michigan.

The difference between the mean pretreatment structural knowledge scores and the mean retention posttreatment structural knowledge scores of each group was also used as a dependent variable. The pretreatment and posttreatment structural knowledge scores for each individual were compared to the score of an expert model of structural knowledge (as represented in the structure of the materials). A tree can be very high in structure and have very little similarity with the "expert" tree. Such a tree indicates a highly developed, individualistic cognitive framework for this content. Another tree can be highly similar to the "expert" tree but only exhibit a moderate degree of structure. Two trees with similar degrees of structure can look very different. A change in the degree of organization does not necessarily indicate the resulting organization is closer to the "expert" one. Nor does a consistent score from pretreatment to posttreatment necessarily mean there is no change. It is possible there is a change in the type of organization, but the same degree of organization is evident.

SAT verbal scores were requested to examine the effect of verbal ability on performance in the different groups. Prior knowledge was assessed using a general physiology test developed by Dwyer for this purpose. Although it does not directly test information on the heart, performance on it has been found to correlate with the performance on the criterion-referenced tests (Dwyer, personal correspondence).

A brief survey to assess attitudes, prior computer experience, prior hypertext experience, and use of the hypertext lesson was used immediately after the treatment. Followup interviews with a sample of learners were conducted by trained interviewers to provide additional qualitative data.

The audit trails for each student were kept by the computer program. This included paths taken and time spent at each point in the program. A count of the number of different screens seen was displayed on each screen and recorded by the computer. The total time spent on the lesson was also recorded.

Procedure

Verbal SAT scores were obtained as a measurement of verbal ability. Before the treatment subjects took a basic physiology prior knowledge test developed by Dwyer, used the ordered-tree technique of Reitman and Rueter (1980) to measure their existing structural knowledge of the concepts in the lesson, and practiced using the navigational technique in the treatment.

For up to an hour, the subjects were provided with four objectives for the lesson and then navigated through as many of the sixty screens in the system as they chose to using one of the three randomly assigned navigational techniques, and then completed an experience and attitude survey and a posttest measuring the ability to construct and label a diagram of the heart, knowledge of facts, identification of concepts, and comprehension. A sampling of the students were interviewed after the treatment. Path data was recorded by the computer for each participant. Approximately two weeks later the students took a delayed retention posttest and completed a second ordered-tree to assess structural knowledge.

Data Analysis

Regression was used to test for the effect of the treatments, the influence of verbal ability and prior knowledge on recall and retention of facts and concepts, comprehension, and structural knowledge, and the interaction between variables and to find the most valid predictor variables; those which account for the most variance in the dependent variables. This was chosen over a multivariate analysis of variance to preserve the maximum amount of data on each independent variable. Multiple regression was used to determine the function that best predicts performance on the each of the dependent variables: immediate posttest, difference between delayed and immediate posttests, posttreatment structural knowledge task, similarity of a subject's structural knowledge to an "expert" representation, difference between pre and posttreatment structural knowledge tasks and to test the effect of the treatments on each of these variables.

The variables representing coverage of the hypertext database (Count) and persistence (Etime) were also included as predictors. In examining the raw data, these variables differed widely among the subjects, so their influence on the dependent variables were also sought to reduce their potential confounding effects.

For each dependent variable, the hypothesized predictors, the potential confounding variables, and the interaction of all these variables and the treatment were regressed. First, parameter estimates were obtained for all the predictor variables and the interactions of these variables with the treatment. Those that were not significant at the .05 level were dropped and the equation refit. The resulting function was the fit for that dependent variable from the predictor variables given, indicating which variables were significant predictors for each dependent variable and what percentage of the total variance of the dependent variable they accounted for as a group (i.e., the multiple correlation coefficient). When interactions between any of the predictors and the treatment were found, equations were fit for each treatment.

A method developed by the researcher was used to compare the paths the students used. This technique was carried out for a sampling of twelve subjects from each treatment. It reported information on how often they went forward or backward, where they clicked, and whether they moved hierarchically, heterarchically, or following the blood flow.

The survey and interview data were summarized quantitatively and qualitatively. Data on prior computer and hypertext use and perceptions were correlated with the test and structural knowledge results.

Results

The three treatment groups showed no significant differences on verbal Scholastic Aptitutde Test scores or prior knowledge of physiology. Groups means showed a difference between the immediate posttest, change from immediate to delayed posttest, posttreatment ordered-tree task, and posttreatment tree similarity to an "expert" tree among the groups.

Subjects in the Hotwords treatment group consistently scored the lowest except in the difference between the pre- and posttreatment trees with those in the Links and Detailed Links groups being more similar to each other. The Detailed Links group generally had the smallest within group variance except on the difference between the immediate and delayed posttests and the difference between the pre- and posttreatment trees (see Tables1,2, and 3). On this latter variable there is a marked difference in the Detailed Links group. They had a very small difference between the pre- and posttreatment scores (i.e., the post scores were only slightly higher).

Table 1
Means and Standard Deviations on Immediate Posttest, Delayed Posttest, and Change in Posttest Scores by Treatment Group

Treatment Group	Immediate Posttest		Delayed Posttest		Change from Immediate to Delayed Posttest	
	M	SD	M	SD	M	SD
Hotwords (n=37)	20.919	(8.207)	17.838	(7.984)	3.081	(4.159)
Links (n=38)	23.237	(8.221)	19.895	(7.266)	3.342	(5.800)
Detailed Links (n=38)	23.658	(7.549)	19.132	(5.757)	4.526	(5.331)
All Groups (n=113)	22.619	(8.016)	18.965	(7.043)	3.655	(5.144)

Note: The change in posttest scores was computed by subtracting the immediate posttest score from the delayed posttest score. A positive number indicates a drop in the score over time.

Table 2
Means and Standard Deviations on Posttreatment Ordered-Tree Task, Change in Structural Knowledge, and Similarity to an "Expert" Ordered-Tree by Treatment Group

Treatment Group	Ordered-Tree Task		Change from Pre to Post Ordered-Tree		Similarity to "Expert" Ordered-Tree	
	M	SD	M	SD	M	SD
Hotwords (n=37)	16.243	(13.621)	2.243	(14.504)	22.162	(20.581)
Links (n=38)	20.158	(14.045)	3.368	(15.958)	33.289	(22.445)
Detailed Links (n=38)	19.579	(11.758)	.058	(11.832)	27.447	(20.201)
All Groups (n=113)	18.947	(13.315)	1.885	(14.139)	27.681	(21.404)

Note: The change in ordered-tree scores was computed by subtracting the pretreatment ordered-tree score from the posttreatment score. A positive number indicates an increase in the amount of structure.

Table 3
Means and Standard Deviations on Number of Screens Seen and Time in Treatment by Treatment Group

Treatment Group	Screen Count		Elapsed Time (in seconds)	
	M	SD	M	SD
Hotwords (n=37)	43.9	(12.7)	1113	(609)
Links (n=38)	45.1	(10.5)	1293	(636)
Detailed Links (n=38)	44.9	(12.7)	1360	(564)
All Groups (n=113)	44.7	(11.0)	1257	(607)

While not included in the hypotheses, both time on treatment (Etime) and number of different screens seen (Count) were included in the analysis since Elapsed Time represents the degree of persistence or use of the navigational tools, depending on how many total screens were seen, and Screen Count represents the actual coverage of the content. The latter indicates the number of different screens seen out of the sixty possible. Although they are highly correlated (r=.61378), both were included.

Immediate Posttest

Multiple regression analysis revealed predictors of performance on the immediate posttest were treatment group, prior knowledge, an interaction of number of screens seen and treatment group, and an interaction of time spent on the treatment and treatment. Approximately sixty percent of the total variance in the criterion variable Test can be accounted for by these predictors (R-square=.604873, F=17.52, p=.0001). The predictors of this variable were then tested for their significance as main effects and in interaction with treatment adjusted for all other variables in the regression (see Table 4).

A significant main effect was found for Prior Knowledge, Number of Screens Seen, Elapsed Time, and Treatment. Because there was a significant interaction between two of the predictor variables and the treatment, equations were determined by treatment. The equation for each treatment is listed in Table 5.

Table 4
Test of Significance of Predictor Variables for the Immediate Posttest Criterion Variable

Source	df	Sums of Squares	Mean Square	F	p
Prior	1	1567.6573	1567.6573	56.78	.0001*
Count	1	159.0293	159.0293	5.76	.0182*
Etime	1	276.0847	276.0847	10.00	.0021*
Treatment	2	190.4967	95.2484	3.45	.0355*
Count*Treat	2	376.6657	188.3328	6.82	.0017*
Etime*Treat	2	248.8115	124.4058	4.51	.0133*

*p<.05

The same predictor variables were not significant in the equations for each of the treatments. Prior Knowledge remained significant in a positive direction in all three treatment equations. Larger beta weights for the same variable, regardless of sign, contribute more to the prediction (Huck, Cormier, & Bounds, 1974, pp. 158), although these numbers should not be used for comparison when the predictors are correlated and not orthogonal as they are in this study (Darlington, 1968). Beta weights cannot be compared across variables due to different measurement scales. For variables such as Elapsed Time, the beta weights were relatively small due to the scale being used (i.e., seconds).

Table 5
Functions for Immediate Posttest for Each Treatment

Equation	R-square	Variable	Parameter	p
Treatment 1	.6656	Intercept	-11.790777	.0326*
(Hotwords)		Prior	1.385386	
	.0001*			
		Count	- .178874	.0636
		Etime	.008288	.0001*
Treatment 2	.6340	Intercept	-13.466263	.0198*
(Links)		Prior	.768232	.0018*
		Count	.340977	.0009*
		Etime	.002544	.1210
Treatment 3	.5164	Intercept	- 9.501131	.1094
(Detailed		Prior	.962467	.0005*
Links)		Count	.236039	.0275*
		Etime	.000085	.9689

*p<.05

A plot of the predictor variable Prior Knowledge against the predicted immediate posttest score showed the positive direction of its influence. It was a significant predictor in all three groups (*p<.05), but there was no significant interaction between prior knowledge and the treatment. The steepest slope, and hence, the strongest influence was evident in the Hotwords group, but this difference was not statistically significant. The Links group had the lowest parameter estimate and the least influence from prior knowledge.

The second significant main effect was the predictor Count which indicated the number out of the total sixty screens each subject looked at in the lesson. There was a significant interaction between treatment and the number of screens seen. The Links and Detailed Links group showed a positive relationship but the Hotwords group showed a small, slightly negative relationship. There was very little difference in the parameter estimates for the Links and Detailed Links groups. The more screens subjects in both of these groups tended to view, the higher their immediate posttest score, whereas, for the Hotwords group, the number of screens viewed did not make a difference.

The Elapsed Time predictor indicated how long each subject spent on the treatment, which may be interpreted as a measure of persistence. Only in the Hotwords group was the predictor variable Elapsed Time significant at the .05 level. Some of this may have been due to collinearity of the predictor variable, in particular the correlation between Screen Count and Elapsed Time. An outlier who viewed the lesson for almost 3500 seconds may have produced the significant effect from Elapsed Time in this treatment where it is not significant in the others.

This analysis for the immediate posttest indicated a significant main effect for treatment at the .0355 level with the Links and Detailed Links scores higher than the Hotwords group. Treatment interacted significantly with the number of screens viewed and the time spent on the treatment. Prior knowledge was a significant predictor of immediate posttest scores in all three treatments, but there was no significant interaction between treatment group and prior knowledge. Students with differing degrees of prior knowledge did not perform significantly different in the three treatments. The predictor Verbal SAT scored used to represent verbal ability did not contribute to prediction of the criterion Immediate Posttest.

Change from Pretest to Posttest

This variable was formed by subtracting the delayed posttest score from the immediate posttest score. A positive number indicates the loss in score. A negative number indicates a higher score on the delayed posttest. Predictors of change in score from immediate to delayed posttest were prior knowledge, immediate posttest score, treatment, and an interaction between verbal ability and treatment (R-square=.386828, F=9.46, p=.0001).

The variables Prior Knowledge, Immediate Posttest, and Treatment were significant (see Table 6). On this criterion variable, the subjects in the Hotwords group (M=3.081) had signficantly less loss in achievement between the immediate and delayed posttest followed by the Links group (M=3.342) and then the Detailed Links group (M=4.526). The work of Phillips and others (1992) showed that the subjects given the least amount of structure performed better on recall. In the current study, those given the least structure performed the worst, but they lost less over time. The pattern of loss supports the statistical concept of regression to the mean over time.

Table 6
Test of Significance of Predictor Variables for the Difference between Immediate and Delayed Posttests Criterion Variable

Source	df	Sum of Squares	Mean Square	F	p
Prior	1	239.49088	239.49088	13.84	.0001*
Treat	2	131.11542	65.55771	3.79	.0258*
Test	1	749.61628	749.61628	43.31	.0001*
Verbal	1	57.14237	57.14237	3.30	.0721
Verbal*Treat	2	136.95793	68.47896	3.96	.0220*

* p<.05

Because there was a significant interaction between one of the predictor variables, Verbal SAT score, and the treatment, equations were determined for each treatment (see Table 7).

Table 7
Functions for the Difference between Immediate and Delayed Posttests for Each Treatment

Equation	R-square	Variable	Parameter	p
Treatment 1 (Hotwords)	.2594	Intercept	11.291464	.0230*
		Prior	- .0547680	.0207*
		Test	.342397	.0022*
		Verbal	- .006322	.4070
Treatment 2 (Links)	.3895	Intercept	-4.437707	.4290
		Prior	- .480898	.0501
		Test	.412299	.0023*
		Verbal	.020062	.0539
Treatment 3 (Detailed Links)	4899	Intercept	-3.736668	.4115
		Prior	- .443104	.0600
		Test	.550589	.0001*
		Verbal	.012112	.1572

*

$p<.05$

Thirteen students actually improved between the immediate and delayed posttests (i.e., two in the Hotwords group, eight in the Links group, and three in the Detailed Links group). The predictor Prior Knowledge contributed to prediction of the change between Immediate and Delayed Posttests. A plot of the predicted difference between immediate and delayed posttest scores for each of the groups showed a slight negative influence of prior knowledge, although the predictor was significant at the .05 level only for the Hotwords group (p=.0207). It approached significance in the Links group (p=.0501) and in the Detailed Links group (p=.0600). There was no significant interaction between treatment group and degree of prior knowledge. This variable represents retention of knowledge from immediately after the treatment to two weeks. A negative parameter estimate here indicates that those with low prior knowledge had a higher difference between immediate and delayed posttest scores. The different treatments did not help or hinder those with low prior knowledge.

Score on the immediate posttest was a significant predictor of the difference between the immediate and delayed posttest scores in all groups. Those who had higher immediate posttest scores tended to decrease more between immediate and delayed posttest than those who had lower immediate posttest scores. The different treatments did not interact with immediate posttest score to influence retention. The influence was strongest in the Detailed Links group followed by the Links group and then the Hotwords group.

Since verbal ability was not significant as a main effect but interacted with treatment, plots of this variable and the predicted value of the criterion variable were drawn for each treatment. Only in the Links group did verbal ability approach significance as a predictor (p=.0539). It was not a significant predictor in the other groups. This may have been due in part to its correlation with prior knowledge which was a significant predictor overall, but did not interact with treatment.

Posttreatment Structural Knowledge

Predictors of posttreatment structural knowledge were pretreatment structural knowledge, an interaction of prior knowledge and treatment, and an interaction of immediate posttest score and treatment. The multiple correlation coefficient predicted about thrity-four percent of the total variance (R-square=.335604, F=5.78, p=.0001).

There was a significant main effect from the pretreatment ordered-tree task. The pretreatment score may reflect both a degree of prior knowledge about the organization of the concepts and a comfort-level with the task itself. These task scores represent the degree of structure, not the structure's similarity to any standard. A student may have a high degree of structure on both the pre- and posttreatment tasks, but the results may represent two entirely different structures. Because there was a significant interaction between two of the predictor variables, Prior Knowledge and Immediate Posttest, and the treatment, equations were determined for each treatment (see Table 9).

Table 8
Test of Significance of Predictor Variables for the Posttreatment Ordered-Tree Task Criterion Variable

Source	df	Sum of Squares	Mean Square	F	p
Treat	2	659.9262	329.9631	2.63	.0767
Tree1	1	1793.5448	1793.5448	14.31	.0003*
Prior	1	298.4925	298.4925	2.38	.1258
Prior*Treat	2	812.3316	406.1658	3.24	.0431*
Test	1	157.3070	157.3070	1.26	.2651
Test*Treat	2	1388.3069	694.1535	5.54	.0052*

*p<.05

Table 9
Functions for the Posttreatment Ordered-Tree Task for Each Treatment

Equation	R-square	Variable	Parameter	p
Treatment 1 (Hotwords)	.3005	Intercept	-23.910117	.0688
		Tree1	.300901	.0939
		Prior	1.893467	.0125*
		Test	- .329488	.3249
Treatment 2 (Links)	.3897	Intercept	3.590528	.7643
		Tree1	.113976	.4983
		Prior	- .501087	.4137
		Test	1.136821	.0009*
Treatment 3 (Detailed Links)	.3477	Intercept	13.722323	.1838
		Tree1	.510772	.0002*
		Prior	- .088868	.8707
		Test	- .086433	.7554

*p<.05

There was a definite linear relationship between pre- and posttreatment scores with those performing higher before the treatment also performing higher after the treatment, but the plot of pretreatment ordered-tree task by predicted posttreatment ordered tree task did not seem to indicate that a demonstrated understanding and ability to do the task before the treatment resulted in much better posttreatment structure. The plot seemed to indicate that the overall trend was to perform slightly worse on the posttreatment task, especially at the higher range of the pretreatment scores. Although there was not a significant interaction between pretreatment and posttreatment orderedtree scores, only in the function for the Detailed Links group was pretreatment score a significant predictor of posttreatment score.

The immediate posttest interacted with the treatment but was not a predictor of posttreatment ordered-tree score by itself. It was a significant predictor only in the Links group. In the Links group there was a definite linear pattern showing a positive relationship between immediate posttest score and predicted score on the posttreatment ordered-tree task. There was no obvious explanation for this one group performing so differently, especially since the Detailed Links group often behaved like the Links group and tended to demonstrate similar patterns. It was expected that the immediate posttest would have some predictive value for the structural knowledge task as structural knowledge is thought to be necessary to answer comprehension questions. Previous studies have not shown it to be necessary for factual recall and, in some cases, have found it to be a hindrance (Jonassen & Wang, 1992).

Prior knowledge interacted with treatment but was not a predictor of posttreatment ordered-tree score by itself. It was a significant predictor only in the Hotwords group. The plot showed a definite positive relationship with higher prior knowledge students doing better on the posttreatment ordered-tree task.

Change in Structural Knowledge

This variable represents the change in structural knowledge from before the treatment to two weeks after the treatment. A positive number indicates an increase in the amount of structure while a negative number indicates a decrease in the amount of structure. Predictors of change in structural knowledge were prior knowledge and pretreatment structural knowledge (R-square=.321461, F=26.06, *p*=.0001). There was no significant interaction between prior knowledge and the treatment, but there was a positive relationship between prior knowledge and change in structural knowledge (*p*=.0131). Those with higher prior knowledge had a significantly greater increase in structural knowledge than those with lower prior knowledge. It is important to remember the previously detailed difficulties with the posttreatment structural knowledge task when interpreting these results.

Table 10

Test of Significance of Predictor Variables for the Difference between the Pretreatment and Posttreatment Ordered-Tree Tasks

Source	df	Sum of Squares	Mean Square	F	p
Prior	1	943.3673	943.3673	6.83	.0
Tree1	1	6820.5012	6820.5012	49.38	.0(

*$p<.05$

A plot of the predicted difference between pretreatment and posttreatment ordered-tree task by pretreatment ordered-tree task showed a negative relationship between these variables. This can be interpreted to mean that the better one did on the initial structural knowledge task, the less difference there was between the pre and post scores on the task to a point. In all the groups, there was a point where the subjects did better on the pretreatment task than on the posttreatment task. About forty-three subjects fall in this area. This loss of structure was most evident in those with higher scores on the pretreatment task.

Structural Knowledge Compared to an "Expert"

The pretreatment and posttreatment ordered-trees of each subject were compared to each other and to the ordered-tree representing the structure of the information in the lesson as created by the instructional developer (i.e., the "expert" ordered-tree) using the program OTSim 1.0 developed by Dr. Henry Rueter at the Cognitive Science and Machine Intelligence Laboratory at the Graduate School of Business at the University of Michigan. This technique computes the Hirtle similarity measure between ordered trees. This is the ratio of the chunks in common and the total chunks of two ordered trees. A similarity measure of 1.0 indicates two identical trees and 0 indicates two trees that are maximally dissimilar. The original similarity scores were multiplied by ten and, therefore, ranged from 100 for identical trees to zero indicating total lack of similarity between two trees. Differences in directionality between two trees do not enter into the measure, so this measures loses some of the information in each tree, but it is the best available at this time. Average similarity measures are shown in Table 11.

Table 11
Mean Similarity Measures for Pretreatment and Posttreatment Ordered Trees Compared to an "Expert" Tree

Links	Overall		Hotwords		Links		Detailed	
	M	SD	M	SD	M	SD	M	SD
Pretreatment /Expert	29.46	(20.09)	27.24	(20.28)	31.76	(19.55)	29.32	(20.56)
Posttreatment /Expert	27.68	(21.40)	22.16	(20.58)	33.29	(22.45)	27.45	(20.20)
Difference between Pre & Posttreatment Similarity Scores	-1.78	(20.86)	-5.08	(19.68)	1.53	(26.30)	-1.87	(15.06)
Pre/Posttreatment Similarity (within subject)	35.74	(28.57)	31.43	(28.30)	37.61	(27.72)	38.08	(29.92)

Note: Pretreatment/Expert is the similarity between a subject's pretreatment ordered-tree score and that of the "expert." Posttreatment/Expert is the similarity between a subject's posttreatment ordered-tree score and that of the "expert." Pretreatment/Posttreatment Similarity is the similarity measure between a subject's pre and posttreatment trees.

Difference between Pre & Posttreatment Similarity Scores is found by subtracting the pretreatment ordered-tree score from the posttreatment score.

The results of this analysis must be interpreted cautiously as the ordered-tree technique proved difficult and/or frustrating for many students. Eight students showed no organization at all in the pretreatment task which may have been due to a lack of knowledge or difficulty with the task. The overall mean structure score was only 17 before the treatment and 19 after the treatment. This could indicate that the task did not discriminate well between students with and without structural knowledge.

Although the statistical analysis indicated no significant difference among the treatment groups on the posttreatment-"expert" similarity scores (F=2.61, p=.0781), there was a marked difference between the Hotwords group and the Links group with the Hotwords group much lower in similarity to the structure represented in the lesson (see Table11). The Hotwords group also demonstrated lower similarity in their pretreatment trees and posttreatment trees (M=31.43). On the average, their posttreatment trees were over five points lower than their pretreatment trees.

The only significant predictor of degree of similarity to the "expert" structure of knowledge presented through the links in the hypertext system was an interaction of immediate posttest and treatment. There was no significant main effect. The multiple correlation coefficient between these predictors and the criterion was .219811 (F=3.47, p=.0014, see Table 12).

Table 12
Test of Significance of Predictor Variables for the Comparison of Posttreatment Ordered-Tree Task and the "Expert" Ordered-Tree

Source	df	Sum of Squares	Mean Square	F	p
Treatment	2	1315.6904	657.8452	1.69	.1896
Prior*Treatment	3	2670.9577	890.3192	2.29	.0830
Test*Treatment	3	5377.1967	1792.3989	4.60	.0046*

*p<.05

A positive relationship between the predictor, Test, and criterion variable was indicated in both the Links and Detailed Links groups, although it was only significant in the Links group (p=.0014).

The interaction of prior knowledge and treatment approached significance , so further analysis was performed. In the Hotwords group, prior knowledge approached significance (p=.0562) which would seem to follow the trend for many of the dependent variables of prior knowledge being most influential in the Hotwords group. It exerted a strong positive influence on the posttreatment similarity score in this group. This also seemed to be indicated by the plot of the Detailed Links treatment, even though it was not significant in that treatment. In the Links group, prior knowledge was not a significant predictor.

Path Data

Coding Schemes

The computer recorded each screen viewed, what order they were viewed, and how long was spent on each screen. To track student usage, a method for classifying each move from screen to screen was developed. The method tracked the screen the user was on currently, the previous screen, and the next screen chosen to determine:

1) if the user returned to the previous screen or went on to a new one;
2) if the user went
   a) up the hierarchy of concepts,
   b) down the hierarchy of concepts,
   c) to a concept across the hierarchy at the same level in the same section,
   d) to a related concept in another section,
   e) to a concept before or after the current one in terms of the flow of blood through the heart,
   f) back to the objectives screen;
3) what position in the map was clicked or, in treatment one, where in the text the clicked word was located;
4) how long a user moved from screen to screen before returning to the objectives screen;
5) how many screens following the blood flow were linked together;
6) how many of the sixty screens were viewed;
7) how many screens were seen more than once;
8) how many screens were viewed in total;
9) how long was spent on the treatment;
10) how many of the instruction screens were viewed;
11) how long the user spent on the instructions; and
12) in what order the user chose to start a new section and how often was each started.

This information was gathered for a random sampling of twelve subjects from each of the treatment groups and collated for each individual. The data were examined in terms of where on the map or in the text the user clicked, what typical moves were made by the user, and how much time was spent on the program.

Number of Screens Viewed

The program contained sixty screens, other than those in the instructions. In the entire sample of one hundred-thirteen subjects, the average number of screens seen by a subject was 45 (SD=12), and they perceived that they saw about 75% of the screens (SD=20) or 42 screens. They spent an average of 1257 seconds or about 21 minutes on the treatments (SD=607 seconds). The groups were largely the same in the average number of screens seen.

Moving Onwards or Returning to the Previous Screen

Subjects had the choice of going on to a new screen from any point, returning to the screen they had just seen, or returning to the Objectives Screen. The groups were largely similar in their movements. In general, the movement was onward to a new screen rather than returning to the screen just seen. To return to a previous screen, the subject had to remember which screen he/she just left and then click on the hotword or button for that screen. There was no "return" or "previous" button. Student ratings of feeling lost correlated with higher rates of returning to the previous screen ($r=.46963$, $p=.0039$) and with a sense of confusion instead of clarity ($r=.30763$, $p=.0682$).

Hierarchical vs. Heterarchical vs. Process Movement

In true hypertext fashion, the user of the program had the ability to link to a wide variety of related concepts from each screen. When the program was constructed, it was divided into four sections, Characteristics, Parts, Circulation, and Blood Pressure, that were all linked to the Objectives Screen. From that screen, the user could go down a hierarchy of concepts in each section. The user also had the ability to move back up the hierarchy and back to the Objectives Screen. In addition, the user could move to related concepts in the same section that were across the hierarchy rather than up or down it. They could also move to a related concept in another section. Users of the program were free to follow their interests, go to familiar concepts, or tackle new ideas. In the Hotwords group, these ideas were all embedded in the text and had to merely be clicked to move to a new screen. The user had to infer the relationships from the other words in the text. In the Links group and in the Detailed Links group the users clicked buttons in the map at the top of the screen to move on to new screens. The Links group merely had the concepts linked together by lines. The Detailed Links group had the nature of each relationship between concepts labeled on the lines.

Although the Links group moved in a slightly more hierarchical fashion and chose slightly fewer heterarchical links, the groups were fairly similar in their movements. Overall, hierarchical movement was the strategy of choice with moving down the hierarchy the most chosen strategy followed by moving across the hierarchy within the section, moving up the hierarchy, and moving across sections. The Hotwords group chose to move across the hierarchy within sections more than the other groups. This could be a function of a lesser awareness of the existence of a hierarchy in the program. With the high percentage of movement down the hierarchy, one might expect a similar amount back up, but this was not the case. The percentage of upward movement was slightly more than half of the percentage of downward movement.

Users tended to start with the first concept on the Objectives screen and work their way through the sections in order. They followed strings of screens ranging from one to over seventy screens in a row, but most followed fewer than thirty screens before returning to the Objectives screen.

Another possible screen selection strategy was to follow the flow of the blood through the heart as one went from screen to screen. Both the previous location and the ensuing location were connected to each screen. Subjects chose this strategy less than 12% of the time and most of these choices were following it only for a screen or two. A button or hotword on each screen led to the part of the heart immediately before and after the current point in the blood flow. Only in the Detailed Links group was this relationship explicitly shown, although those in the other two groups could determine this through reading the text itself. The patterns of screen selection following the blood flow do not differ greatly among the groups.

Click Locations

Another explanation for movements though the screens was that students selected the screen to go to next, not by the content, but by the placement of the hotword in the text or the button on the map. Subjects in the Hotwords group did tend to choose words near the beginning of the text. The low numbers at the bottom of the list are partially a function of the few screens that had that many words. There is not an indication that they chose only the first word, so placement alone does not appear to explain choice of screens.

Subjects in the Links and Detailed Links groups used the map at the top of the screen to navigate. The word at the top of the map was always the concept one step up in the hierarchy. Only concepts directly connected to the current screen were shown. The other terms around the current concept button were not necessarily arranged in a hierarchical fashion, although related terms were placed symmetrically (e.g., Right Auricle was opposite Left Auricle under Auricles). The two groups generally chose locations in the same proportions. The first counterclockwise position (upper left corner) was chosen most often, followed by the top position which was one step up in the hierarchy. This follows the research that people in Western cultures tend to work from the upper left corner of a screen to the lower right. The first clockwise position (upper right) was chosen third most often followed by the second clockwise position and then the second counterclockwise position. Most screens had at least these positions, so these generalizations probably can be made. Anything beyond this is largely a function of how often that position appeared in the map. It does appear that position was a factor in selection of the next concept.

Attitudes and Experiences

Before logging off the computer in session one, each participant completed a survey on the computer concerning his/her previous computer experience, perceptions of moving through the program, and preferred learning strategies. Most items were 5-point Likert-type scales (1=low, 5=high).

The majority of the students did not feel computers were very important in their daily lives and few used computers daily. Students rated the use of hypertext for learning as moderately confusing. Students indicated that they found the program somewhat overwhelming. This feeling appeared similar across all groups. Related to this overwhelming feeling, many students indicated that it was relatively easy to get lost ($\underline{M}$=3.37). No one group appeared to have this feeling more than any other. On the other hand, the Links group appeared to find the program slightly more effective than the other groups. Students felt the program was harder than text ($\underline{M}$=3.21) with the Hotwords and Detailed Links groups especially leaning in that direction.

Students were asked to comment on the program as an educational strategy. Of the 59 who chose to respond, fourteen commented favorably, noting the ability to go back for review and self pacing as positive aspects. Several students commented that this new form of presenting information takes some getting used to. Many described the experience as confusing, frustrating, overwhelming, and long. Some felt it provided too many options and no logical order. One student stated, "...it bothered me that it was not easy to see the hierarchical structure behind the material. Obviously some material would be more important than others in any given lesson. I found that this program seemed to make the basic structure unclear." A number of others found the heart content boring or too technical. Many felt they missed some screens and easily got lost. In contrast to earlier statements, some found it impossible to use for review because the navigation was very difficult. A few expressed a general dislike of working with computers and/or a preference for textbooks.

Searching Strategies

Students were asked to estimate how much of the program they had covered. A counter indicating how many of the 60 different screens a student had seen was located in the upper right corner of each screen. A Pearson's Product Moment Correlation was performed on the number of different screens and the percentage estimated seen. There was only a correlation of .35494 ($p=.0337$) between these two measures, indicating the students did not take full advantage of this counter and had no intuitive idea of the size of the program.

All students indicated they sometimes did not go to screens they already felt they knew. Few indicated a willingness to skip such screens often. This may indicate the students either had little knowledge of the topic, could not judge what was on the next screen, or were unwilling to miss anything. Students indicated they sometimes went to concepts familiar to them which may also indicate a hesitancy to miss anything. Interesting, there was a positive correlation between amount of prior knowledge and number of screen seen ($r=.28031$, $p=.0977$). Students with higher prior knowledge had a slight tendency to view more screens. Students felt sometimes they viewed screens they had seen before, often unwittingly, but also felt they sometimes missed screens that they skipped and then never could find again.

Almost half (10 out of 22) admitted to having some problems with the lesson such as confusion due to flipping through so many screens, problems with so many options, and trouble finding missed screens to an inability getting back to where one wanted to go. Students expressed their difficulties:

> It was kind of confusing. There were several choices each time you went, and every time you picked a choice, then it would take you off in a totally different direction then you were looking at to begin with. (Hotwords group)

> Sometimes I couldn't get back or had a hard time getting back to where I wanted to get back to. The checks were a good idea. Otherwise I would have gone back to things two or three times by mistake. (Links group)

The navigational techniques used and the degree of learner control were new to most students, and many had difficulty adapting. The majority of the students (i.e., eighteen out of twenty-two) did not find the navigational technique distracting. Some felt it gave the main points to be learned. As one student put it:

> It gave me an idea of what the main points were, some of the more important information, so I'd look at those. I'd read through the text and then go back to the one I'd have the most trouble with or that would interest me the most. Then I'd go back and fill in the gaps and read the stuff I wasn't too sure of. (Hotwords group)

A few found it confusing. Two stated they read the text and then looked at the map, but one felt it made her want to move on without reading the text.

When asked about the strategy they developed to move from screen to screen, the majority said they had a strategy, although their definitions of a strategy varied. Students based their selections on prior knowledge, on an attempt to cover all screens, by relationship, or by locational cues rather than content oriented cues.

When describing the development of these navigational strategies, most tended to start with one technique and stick with it. They tended to use the asterisks or checks indicating screens already seen to determine what they had covered and went back to the Objectives screen to restart when they hit a dead end or got lost. Many never really figured out how to move back through screens.

When asked if they skipped screens on concepts they already knew, nine admitted doing that with three more saying they skipped just a few. Ten never skipped any screens. Many said they wanted to look at all the screens. Some said they went over those they knew more quickly, and a few began to skip or quickly skim screens when they realized they knew some of the information. Many said they went to the familiar screens first and then tried to relate the new screens to the familiar. Some of this hesitancy to skip screens may have been due to the fact that the subject was new to most subjects.

Twenty of the subjects interviewed said they reread screens by choice, especially if they did not understand the topic originally. Twelve of the subjects said they reread screens by accident.

Learner control was a concept fairly new to most of the subjects. They were evenly divided on a preference for learner control or lesson control. Those that liked learner control said they liked the choice so they could skip what was known, review as necessary, and focus on interests. They felt is involved them more in learning. Those that favored lesson control said it provides necessary organization so the learner knows what is important, doesn't waste energy in organizing the content, and provides a logical order for the information. Several felt lost navigating on their own. Others felt they might miss important information, especially on a subject new to them.

Those in the Detailed Links group were asked about their use of the labels in the graphical browser. Five of the seven said they read the labels, although most said they did not do it all of the time. If this is the case, subjects in this group and subjects in the Links group were often performing in the same fashion, thereby minimizing the effects of the two treatments.

At the beginning subjects had been asked to think of the lesson as a new way of learning. They were asked to list the good and bad points of this way of learning. Good points included 1) it was different and interesting; 2) it provided many choices and the chance to skip or review as desired; 3) it provided learner control to choose when and in what order screens were read; 4) it interactively involved the learner and was less boring; 5) it gave the structure of the information in the map; 6) it included useful diagrams; 7) there was a small amount of information on each screen; and 8) it was less time consuming than reading. Some of these strengths were weaknesses to other subjects. Negative aspects of this way of learning mentioned included: 1) it allowed a lot of skipping around; 2) navigation was hard, often confusing, and difficult to move back and forth; 3) it did not provide a concrete order for the information or emphasize the most important information; 4) it is difficult for those with little background knowledge; 5) use of the computer itself was distracting; 6) it was possible to go through it quickly and not learn the information; 7) it was hard to keep track of what was covered; 8) it was not an interesting topic; 9) the amount of information was overwhelming; and 10) not everyone has access to a computer. Overall, students felt there were possibilities for this type of learning but it was confusing and did not provide enough structure for the information.

Limitations of the Study

Testing was a threat in this study. The immediate and delayed posttests were alternate versions of the same test possibly causing some improvement in the delayed test due to the subjects' experience with the immediate posttest. Another threat to internal validity was the method for assessing structural knowledge. Most students are not familiar with such assessment methods and have trouble carrying them out. Mean scores for the task were only 17 out of 44 (SD=13) before the treatment and 19 (SD=13) two weeks after the treatment. Some students produced trees with no or very low structure either before or after the treatment.

A low correlation was found between the posttreatment ordered-tree measuring the structure of a learner's content information and the immediate and delayed criterion-referenced tests (r=.33156 for the immediate posttest, r=.36401 for the delayed posttest). This is another possible indication that the orderedtree task did not differentiate well between the subjects. The question of whether focusing on the concepts and their relationships helps or hinders recall of facts has emerged in the research. Jonassen and Wang (1990) showed that stressing this type of learning may actually hinder factual recall. In the present study, the students did not do worse on the posttests than in similar studies with print materials, but the structural knowledge tasks did not show a large acquisition of this type of knowledge.

The comparisons to an "expert" structure were conducted using the structure of the content in the lesson. This "expert" tree was constructed by the instructional developer and should not be considered that of an expert in the field, but rather that represented in the lesson. It was verified by a high school biology teacher and a nurse for accuracy. The similarity ratings must be interpreted with caution as there are numerous valid ways to structure this information. Each individual may go through the lesson and construct different personal structures.

The ordered-tree technique also may have influenced the study by alerting subjects to important concepts. As these terms were not all that was evaluated on the posttest, they may have provided a false sense of security in selecting what to study. Many seemed to put little effort into it at the time of the delayed posttest.

Experimental mortality was a problem, with twelve students not completing the first session, ten not returning to the second, and five dropped due to lack of SAT scores. Even with this problem, the groups ended up with almost equal numbers, although it is not known if the students lost were randomly distributed across all independent variables.

Generalizability or external validity threats were also present in this study, most notably the fact that volunteers who did this for extra credit, not as part of class content, were used.

Another problem was the length of treatment. The idea was to work within a constrained subject domain so that all the subjects had the possibility of going through all the material. Students not interested in a scientific topic may have found even the time spent boring. Twelve subjects chose to view only one or two screens before exiting. At the same time, the experience with the different types of structural knowledge representations may not have been enough to see an effect, nor were the students actively involved in generating the structural frameworks.

Multiple regression was used for exploring the data in this study. For the equation estimated for the immediate posttest the multiple correlation coefficient was fairly high, accounting for sixty percent of the variance in the dependent variable, but for the other equations, the multiple correlation coefficient was between thirty and thirty-five, accounting for only that percentage of the variance in the dependent variable. The low multiple correlation coefficients could be due to omitting relevant predictor variables, including irrelevant variables, and/or using variables in an incorrect form when the relationships are non-linear. All are possible in this study with the most likely being omission of relevant variables. Other individual cognitive differences, experience with hypertext, risk-taking behavior, and motivational factors might be likely predictors of performance.

Conclusions and Recommendations

This study suggests that users of hypertext require extended experience with such a system to become comfortable and proficient using it. Graphical browsers may provide a degree of structure for the user, but it was not evident from the results that all learners internalized this structural knowledge. Those with high prior knowledge did better on most variables and showed a greater increase in structural knowledge. The use of hotwords rather than a graphical browser resulted in lower achievement on the criterion test dependent measures and was a special problem for those with lower prior knowledge. Verbal ability was not a factor on most of the variables. Further research incorporating extended hypertext use may help to determine the best methods for aiding learners to acquire knowledge in a hypertext system.

Effect of Using Different Navigational Techniques

On both the immediate posttest and the change between immediate and delayed posttests treatment was a significant predictor. The Hotwords group was forced to generate their own framework for the knowledge because the words were embedded in the text, not arranged relationally. It was this group that consistently performed the lowest on all dependent measures. This group's performance was also the most influenced by degree of prior knowledge, most notably on the structural knowledge dependent variables. The Links and Detailed Links groups who used the two different forms of the graphical browser performed similarly on several of the dependent measures, perhaps due to the members of the Detailed Links group who did not consistently read the labels in the graphical browser.

Additional individual subject variables interacted with the treatments, indicating that no one treatment was best for all subjects. The contribution of these variables differed on the various dependent measures.

Influence of Prior Knowledge

Prior knowledge was a significant predictor of immediate posttest score, the difference between delayed and immediate posttest scores, and the difference between pretreatment and posttreatment ordered-tree task scores. It was not a significant predictor of the posttreatment ordered-tree task score itself.

Prior knowledge did not interact significantly with the treatment on any of the dependent measures except the posttreatment ordered-tree task. On this variable it was significant only in the Hotwords group. It was significant only in the Hotwords group for dependent variables representing the difference between posttest scores. This may indicate that learning using the Hotwords treatment which was less obvious in its portrayal of the content structure was more difficult for students with lower prior knowledge as evidenced by several of the dependent measures. The treatments that provided more structural knowledge support appeared to be less influenced by degree of prior knowledge. This study suggests further research on methods for compensating for low prior knowledge is warranted.

In an examination of the path information, students with higher prior knowledge tended to view more of the total number of screens. This may reflect a greater interest in the topic or the general unwillingness to skip screens, even if the information was known. Those with lower prior knowledge may have experienced more frustration and exited the lesson more quickly. Research on learner control has shown that learners often do not know what is best for their own learning, and, even if they do, may not act on this knowledge (Milheim & Martin, 1991; Jonassen, 1986). This is a special problem for those with low prior knowledge (Steinberg, 1977; Milheim & Martin, 1991). Even college students have difficulty with this self-assessment (Garhart & Hannafin, 1986).

In the interviews, less than half said they skipped any of the screens they already knew and of those, most skipped only a few. More common was the tendency to look at a screen and go over it quickly if the content was already known. A number of students indicated they used their prior knowledge to begin with familiar screens and then tie new screens to this known information.

Comparisons of subjects' and the "expert" ordered-trees showed no significant influence of prior knowledge, although it approached significance in the Hotwords group and appeared in a general positive direction in the Detailed Links group.

Influence of Verbal Ability

Verbal ability was not a major influence on most of the dependent measures, possibly due to its correlation with the independent variable Prior Knowledge. Only in the difference between the immediate and delayed posttests did it prove significant, and then only in interaction with the treatment.

Influence of Time on Treatment and Number of Screens Seen

Time spent on treatment and number of screens seen contributed to the variance in scores on the immediate posttest only. Treatment group interacted with both variables so that subjects in the three groups performed differently on the immediate posttest as influenced by these two variables. Number of screens seen contributed significantly only in the Links and Detailed Links groups, approaching significance in the Hotwords group, while time spent on treatment contributed significantly only in the Hotwords group.

Many subjects did not view all the screens due to fatigue or boredom, a choice of degree of effort to invest, or accidentally missed screens and an inability to find them again. Subjects viewing significantly under the sixtyscreens may not have covered all the information evaluated in the posttest. The number of screens seen made a difference on posttest scores for the Links and Detailed Links group, but not for the Hotwords group where there was a very slight negative influence from the number of screens seen.

Time spent could represent either persistence in finding all the screens and/or amount of time spent reading the screens. The latter may have been important only in the Hotwords treatment because more persistence may have been required to actually see all the screens. The screens covered were marked with asterisks within the text itself, but this indication may not have been as obvious to the subjects as the checkmarks used in the graphical browsers. It was surprising that those at the low end of the time variable did as well as they did on the test, considering they spent such a small amount of time viewing the screens. Some of the elapsed time was spent on navigation, as a number of students spent the last few minutes looking for screens they had missed rather than reading new material.

The effect of these two variables was not evident in the change from immediate to delayed posttest. Simply viewing the more screens quickly might influence immediate recall of the information, but not allow for integration of this information into long term memory. Viewing more screens did not translate into a proportionally long time spent on the treatment.

Changes in Structural Knowledge

The posttreatment structural knowledge scores in this study did not rise from the pretreatment scores for all subjects nor did they necessarily grow closer to an "expert" structure reflected in the lesson. Those with high initial structural knowledge showed the highest posttreatment scores, especially in the Detailed Links group. It is conceivable that some of these students may have used the pretreatment task as an organizer for the new information, particularly because the graphical browsers in this group spatially portrayed some of the same terms used in the task and indicated their relationships.

Those who showed greater pretreatment structural knowledge actually did not gain, but lost structural knowledge from the pre to posttreatment task. Some of this may be attributed to the statistical phenomenon of regression to the mean. There may also have been some problem with degree of effort expended on the posttreatment task. Another possible explanation could be that some students who had a structure before the task were caused to question that structure after exposure to the structure in the lesson but never integrated this new structure into their schema. On the other hand, those who did better on the immediate posttest tended to demonstrate more similarity to the "expert" ordered-tree, especially in the Links and Detailed Links groups. This reaffirms the idea that degree of structure is not synonymous with similarity to the "expert" structure. Students may have lost some of their original structure which was unlike the one in the lesson and moved closer to that portrayed in the lesson, but never reaching the same degree of structure shown initially.

Further research is needed on the relationship between declarative knowledge as measured in the immediate and delayed posttests and structural knowledge measured by the ordered-tree task. If declarative knowledge is embedded in structural knowledge, one would expect a closer correlation in all groups between the immediate posttest and the posttreatment ordered-tree and between the delayed posttest and the posttreatment ordered-tree. Students who learned the relationships between the concepts in the lesson would have also learned facts about those concepts. If, as Jonassen and Wang (1992) stated, one interferes with the other, e.g., the acquisition of the relationships between concepts interferes with learning details about the concepts, a negative relationship would be predicted between scores. In this study, the correlation between the immediate posttest and the posttreatment structural knowledge task was only .33 and between the delayed posttest and the posttreatment structural knowledge task only .36.

Problems in Learning from Hypertext

In general, students in all treatments expressed some confusion in going through the treatments. Complete learner control over the pace and path of information seen was new to most of the students. Many felt lost and frustrated as they tried to work their way through the many options on each screen and formulate their own structure. Only after sustained use of such a system for a period of time do users become comfortable with this control and develop the strategies needed to make selections and follow subject paths (Landow, 1990; Oren, 1990; Remde, Gomez and Landauer, 1987; Marchionini, 1988).

This study's subjects spent an average of only twenty-one minutes on the lesson. Many, in fact, spent as much if not more time on the testing. They viewed an average of forty-four of the sixty possible screens. This was not a long-term involvement with hypertext that would be needed for familiarization with the technique. Multiple trials with navigation through a hypertext system should better prepare the subjects to direct their own learning through such a system.

Hypertext use also can cause an additional cognitive burden by requiring users remember the links just made and connect all this information into a coherent whole. Users also had to discover and remember the consequence of following a certain path, where it led, and types of information it provided (Heller, 1990). Examination of path data showed a few students restarting the same section a number of times, only to terminate this path quickly, possibly because he or she decided it was something previously covered. Perhaps some way of indicating what percentage of the screens seen under any of the four main section headings would help in this decision making.

Although the counter in the upper right corner indicated how many of the total number of screens had been seen, there was no indication where the remaining screens were located. This may not be a problem if the system is used for locating information for a specific information need, but students intent on seeing all the screens in an instructional situation became frustrated and jumped around searching for a few missing screens.

This additional cognitive load can distract from the content of the lesson (Mayes, Kibby, and Anderson, 1990). Only one student interviewed specifically mentioned distraction from the use of the graphical browser, although several mentioned they found the browser difficult to use and found keeping track of where they had been a burden. The lack of normal reading cues added to the difficulty of using such a system, especially for less skilled readers (Charney, 1987, Horn, 1990). Only two of the students interviewed stated that the graphical browsers consciously indicated the structure of the content to them, and just a few said they used that structure to help them decide where to go next. This could indicate a lack of understanding of the maps themselves or a lack of attention to these cues presented in a fashion unfamiliar to the students.

The sheer amount of information presented and the number of decisions that needed to be made could also have been distracting to the user. A number of those interviewed mentioned the difficulty of dealing with so many options and this was listed as a reason for preferring lesson control by several. The students were given four major objectives on the first screen that formed the basis for the organization of the hypertext screens, but many did not appear to use these in their searching. The lack of a clearly evident structured path through the screens may have caused students who did not develop a strategy to wander aimlessly, miss relevant material, or form a wrong interpretation (Marchionini, 1988). Perhaps with such a short exposure, the subjects did not have the chance to develop the needed skills in navigating, absorbing layers of information, integrating new information with existing knowledge, gaining a comprehensive picture of the subject, self-management, searching, and manipulation of the interface needed for hypertext systems (Bourne, 1990; Jonassen, 1989b; Kinzie & Berdel, 1990; Wright, 1990; Marchionini, 1988).

Motivation could also have been a problem in this study, carried out with volunteer subjects who had no stake in learning the content. Their only extrinsic motivation was to show up for two sessions to get extra credit points as the content was not related to their classwork. The content of the heart was not of great interest to a number of those interviewed. With motivation an issue and the lack of focus on the objectives given, some students may have merely rambled through the system when given complete learner control (Hammond, 1989) and may have exited the program before covering all the material.

Milheim and Martin (1991) suggested that allowing the learner to control the sequence of the content may not be effective when the content has a specific prerequisite order. They also suggested if all topics must be covered to successfully complete the program or when topics have a hierarchical order, learner selection of content to be covered is not effective. The results of this study cannot strongly support or repudiate these claims, but the mean scores on the criterion-referenced posttest were equal to or slightly higher than those in studies using the linear, print form of the materials when adjusted for test length (e.g., Hodes, 1990; Cardinale, 1990). No comparable measures of structural knowledge are available.

This hierarchically structured content may not have been the most appropriate for a hypertext system. Duchastel (1990) and Spiro and Jehng (1990) have suggested that hypertext is not appropriate for highly structured learning tasks where students may benefit from having that structure explicitly provided to them. Students are not presented the information in the most logical sequence, nor are facts and lower level concepts mastered before higher level ones (Gagne, Briggs, & Wager, 1988). They are left to discover this structure on their own, a task especially difficult for those with no prior knowledge on the topic. The whole question of whether or not the structure of the system was ever conveyed to the subjects must be raised. The low mean scores on the posttreatment ordered tree task (M=17) indicated either a lack of understanding of the content structure, a lack of understanding of the task or frustration with the task.

Students interviewed expressed some difficulty in discovering the major concepts first. The system was structured so that the user could move down the hierarchy of concepts, but this may not have been obvious to all. Users could cover all the main concepts first and then delve into each in more depth as desired. This may be one type of recommended hypertext use strategy that requires more explanation or instruction for the user.

Learning the process of the blood flow through the heart was also an aspect of this lesson. Such a linear process can be less obvious in a non-linear system unless it is clearly delineated. If hypertext is to be used to learn the steps in a process, the steps need to be more clearly linked in the proper order.

Search Strategies

Students were asked about their search strategies, both in the survey and in the interviews and their path data was analyzed. In the survey, they said they returned to the previous screen, saw screens more than once, and missed seeing some screens they wanted to get back to "sometimes" to "often" on a five point scale (i.e., never, sometimes, often, most of the time, always). Analysis of the path data of a sampling of thirty-six subjects showed that they returned to the previous screen about ten percent of the time, going on to a new screen eighty-four percent of the time and returning to the main Objectives screen six percent of the time. A number of students never appeared to grasp the concept of moving back through a path.

The largest percentage of movement in all groups was down the hierarchy with hierarchical movement the most common overall. The highest percentage of options in the graphical browsers was down the hierarchy, so this was expected. The Links group performed slightly more hierarchical movements and fewer heterarchical movements when compared to the other two groups. The Hotwords group tended to move across sections more, possibly because the structure was less visible. Only twelve percent of the movements across all groups followed the flow of blood and much of this was just one screen to the next, not a long string of screens following the blood flow. Students either did not see this as an option or chose to follow the more obvious hierarchical framework of the lesson.

Movement across the hierarchy was largely confined to within a section rather than jumping across sections to related concepts. Even without a strict hierarchy indicated in the navigational technique, students tended to follow a natural hierarchy, although some students indicated in the interviews that they had a hard time perceiving the structure of the content. In learning a process such as the flow of blood through the heart, this hierarchical movement may be most useful for learning the parts of the heart, but not for learning the actual process. If students are to follow this blood flow, it must be more clearly delineated in the choices for navigation.

Where the students clicked on the screen was also recorded to determine if actual placement on the screen was a factor in choosing where to go next rather than the actual content itself. Those in the Hotwords treatment tended to choose the top three words in the text, although not selecting the top term any more often than the others. The groups with the graphical browser tended to select the term in the upper left corner most often, followed by the term at the top then the term in the upper right corner. This may indicate the tendency to start reading in the upper left corner and proceed to the lower right. In general, the terms on the left side of the graphical browser were selected more often that parallel terms on the right side. Placement on the map may be just as important in selection of the next screen as content. If the hierarchy were more evident in the browser, perhaps this would be less the case.

Implications for Instructional Design

No one technique proved best for all students. When compared to other studies by Dwyer using the same materials in a written form, the scores on the criterion-referenced posttests were not greatly improved, although results were better than some dissertation studies using print versions of the heart materials (e.g., Hodes, 1990; Cardinale, 1990), nor time saved by this instructional method (Dwyer, personal correspondence). No comparisons on the structural knowledge task were available. Individual differences, such as prior knowledge, accounted for much of the variance in learner achievement.

In general, the use of this hypertext system was not intuitive for first-time users. Students not used to this degree of learner control often felt lost and confused. Many had trouble developing a viable strategy for moving through and organizing the information. Many used the indicators of screens already seen (i.e., asterisks or checkmarks) and number of different screens shown in the upper right corner, but still had trouble moving back through a path and selecting from the many options on a screen.

Several suggestions are made for structuring a hypertext system for learning.

1. Results suggest that the graphical browser would be a better navigational tool than the use of the Hotwords alone, especially for those with lower prior knowledge.
2. Students had difficulty getting back to where they came from. Techniques such as path histories of recent screens, an indication of the immediate previous screen, a thumbnail of the previous screen, or a "return" arrow to go to the previous screenmight be useful.
3. The graphical browser could be structured to better represent the types of relationships. Terms up and down the hierarchy might be differentiated from those that jump to other sections or those that follow the flow of blood.
4. A global map or web view showing areas covered and relationships beyond the immediate screen and its direct links could be made available with the ability to zoom in or out to a global map.
5. Some way of indicating what percentage of the screens seen under any of the four main section headings would help in deciding how much of each section has been covered.
6. Not all students work well with a graphical representation of the content structure or prefer this method of navigating, so providing some type of menu listing might be more appropriate for these users.It might be possible to give the user a choice, but this decision may be difficult for the naive user.

7. Users with low prior knowledge or those with little experience with this type of system may need additional guidance in their initial use of the system. Possibly a type of guided tour which would highlight the major concepts to be covered first would be useful for an overview (Oren, 1990). Such guidance could be available on demand in a menu or pop-up window to recommend a path, next step(s), and/or strategy. Novice and expert users of the system may prefer different degrees of guidance.
8. Some additional method for getting to missed screens is needed, perhaps integration of information on missed sections or screens into an overview map or diagram.
9. A keyword search capability would be useful for those looking for a specific piece of information.
10. Hypertext on its own is not necessarily instructional. Such a program might be best used as part of a large instructional system where learners are either given or develop specific objectives for using the system.
11. Highly structured information which might be easiest to learn in a specified order may best be taught in another fashion. Processes may also benefit from a more structured system with more limited hypertext features.
12. An online notebook could be used for taking notes, copying information from the screen, incorporating prior knowledge and information from other sources, and/or keeping track of the knowledge structure or path covered.
13. Students interviewed did not show a desire to provide their own labels on the graphical browsers, but this generative activity might be included as part of the instructional system. It would also draw students' attention to the graphical browser and its structural knowledge content.

Suggestions for Future Research

This was an exploratory analysis designed to determine some of the important variables in the use of hypertext systems for learning. Variables such as prior knowledge and number of screens seen warrant inclusion in future studies. Several suggestions for future research follow.

1. Improve the use of the ordered-tree technique for assessing structural knowledge or explore other possibilities for this assessment. Students need greater familiarity with the technique and practice in its use beforehand.
2. Compare the acquisition of structural knowledge in this technique to using the print form of the lesson. If there is no gain on any of the dependent measures using the hypertext version, there may be little reason to invest the effort in its development unless skills such as information-seeking and comprehension monitoring in a non-linear environment are to be developed.
3. Using the same basic research design, expand the study for use in a real life setting with content appropriate for class use.
4. Further explore the use of different types of graphical browsers.
5. Incorporate further investigation of search strategies both through

qualitative data and analysis of path data in long-term studies. Comparisons of novice and expert users could help describe the development of usable strategies.

6. Assess motivational and attitudinal issues in the use of these systems as well as other individual differences such as risk-taking behavior, field articulation, and metacognitive ability. Look at specific aspects of reading ability that may affect hypertext use.
7. Look at the relationship between structural knowledge, factual knowledge, and problem solving.
8. Study the use of hypertext systems for learning in younger students and the cognitive demands of such a systems.
9. Investigate other navigational methods for using hypertext systems and their relationship to structural knowledge. Study how these systems can replicate or replace traditional reading cues.

eferences

Anderson, R.C. & Pearson, P.D. (1984). A schema-theoretic view of basic processes in reading comprehension. In P.D. Pearson (Ed.), Handbook of reading research, Vol. 1 (pp. 255-291) NY: Longman.

Armbruster, B.B. & Anderson, T.H. (1985). Frames: Structures for informative texts. In D.H. Jonassen (Ed.), The technology of text, volume _ (pp. 90-104). Englewood Cliffs, NJ: Educational Technology Publications.

Beissner, K.L., Jonassen, D.H., & Grabowski, B.L. (1993). Using and selecting graphic techniques to convey structural knowledge. Paper presented at the annual meeting of the Association for Educational Communications and Technology (New Orleans, LA, January 1993).

Bourne, D.E. (1990). Computer-assisted instruction, learning theory, and hypermedia: An associative linkage. Research Strategies, 8(4), 160-171.

Breuker, J.A. (1984). A theoretical framework for spatial learning strategies. In C.D. Holley & D.F. Dansereau (Eds.), Spatial learning strategies: Techniques, applications, and related issues (pp. 21-46). NY: Academic Press.

Bruner, J. (1960). The process of education. Cambridge: Harvard University Press.

Cardinale, L.A. (1990). The effect of varied types of embedded explication on the delayed achievement of different educational objectives using text-based instruction. Unpublished doctoral dissertation. The Pennsylvania State University, University Park, PA.

Charney, D. (1987). Comprehending non-linear text: The role of discourse cues and reading strategies. Hypertext /87, pp. 109-120.

Chiesi, H.L., Spilich, G.J., & Voss, J.F. (1979). Acquisition of domain-related information in relation to high and low domain knowledge. Journal of Verbal

Learning and Verbal Behavior, 18, 257-273.

Clark, S.R. (1990). Schema theory and reading comprehension. (ERIC Document Reproduction Service No. ED 325 802).

Conklin, J. (1987). Hypertext: An introduction and survey. Computer, 20, 17-41.

Darlington, R.B. (1968). Multiple regression in psychological research and practice. Psychological Bulletin, 69(3), 161-182.

Denenberg, S.A. (1988). Semantic network designs for courseware. In D.H. Jonassen (Ed.) Instructional designs for microcomputer courseware (pp. 307-326). Hillsdale, NJ: Erlbaum.

Doland, V.M. (1989). Hypermedia as an interpretive act. Hypermedia, 1, 6-19.

Duchastel, P.C. (1990). Discussion: Formal and informal learning with hypermedia. In D.H. Jonassen & H. Mandl (Eds.), Designing hypermedia for learning (pp. 135-143). Berlin: Springer-Verlag.

Duffy, T.M. & Knuth, R.A. (1990). Hypermedia and instruction: Where is the match? In D.H. Jonassen & H. Mandl (Eds.), Designing hypermedia for learning (pp. 199-225). Berlin: Springer-Verlag.

Dwyer, F.M. (1978). Strategies for improving visual learning. State College, PA: Learning Services.

Dwyer, F.M. and Lamberski, R. (1977). The human heart: Parts of the heart, circulation of blood and cycle of blood pressure. Unpublished manuscript.

Fincher-Kiefer, R. (1992). The role of prior knowledge in inferential processing. Journal of Research in Reading, 15(1), 12-27.

Gagne, R.M. (1986). Instructional technology: The research field. Journal of Instructional Development, 8(3), 714.

Gagne, R.M., Briggs, L.J., & Wager, W.W. (1988). Principles of instructional design. 3rd ed. NY: Holt, Rinehart, & Winston.

Garhart, C. & Hannafin, M. (1986). The accuracy of cognitive monitoring during computer-based instruction. Journal of Computer-Based Instruction, 13, 88-93.

Gay, G. (1986). Interaction of learner control and prior understanding in computer-assisted video instruction. Journal of Educational Psychology, 78, 225-227.

Halasz, F.G. (1987). Reflections on NoteCards: Seven issues for the next generation of hypermedia systems. Hypertext '87, pp. 345-366.

Hammond, N. (1989). Hypermedia and learning: Who guides whom? In G. Goos and J. Hartmanis (Eds.), Lecture notes in computer science: Computer assisted learning (pp. 167-181). Berlin: Springer Verlag.

Heller, R.S. (1990). The role of hypermedia in education: A look at the research issues. Journal of Research on Computing in Education, 22, 431-441.

Hodes, C.L. (1990). The induction, use, and effectiveness of imaginal processes as a cognitive strategy. Unpublished doctoral dissertation. The Pennsylvania State University, University Park, PA.

Horn, R.E. (1989). Mapping hypertext: The analysis, organization, and display of knowledge for the next generation of on-line text and graphics. Lexington, MA: Lexington Institute.

Huck, S.W., Cormier, W.H., & Bounds, W.G., Jr. (1974). Reading statistics and research. NY: Harper and Row.

Hunt, E. (1983). The next word on verbal ability. Paper presented at the annual meeting of the American Educational Research Association (Montreal, Canada, April 1983) (ERIC Document Reproduction Service No. ED 236572).

Jonassen, D.H. (1986). Hypertext principles for text and courseware design. Educational Psychologist, 21(4), 269-292.

Jonassen, D.H. (1989). Hypertext/hypermedia. Englewood Cliffs, NJ: Educational Technology Publications.

Jonassen, D.H. (1990). Structural knowledge. Paper presented at the annual meeting of the Association for Educational Communications and Technology (Anaheim, CA, February 1990).

Jonassen, D.H. (1991). Generative processing of structural knowledge in hypertext. Paper presented for the annual meeting of the Association for the Development of Computer-Based Instructional Systems (St. Louis, MO, November 1991).

Jonassen, D.H. & Wang, S. (1990). Acquiring structural knowledge from semantically structured hypertext. Paper presented at the annual meeting of the Association for the Development of Computer-Based Instructional Systems (San Diego, CA, October, 1990).

Jonassen, D.H. & Wang, S. (1992). Acquiring structural knowledge from semantically structured hypertext. Paper presented at the annual meeting of the Association for Educational Communications and Technology (Washington, DC, February 1992).

Jonassen, D.H. & Wang, S. (1993). Acquiring structural knowledge from semantically structured hypertext. Journal of Computer-Based Instruction, 20(1), 1-8.

Jones, W. (1987). How do we distinguish the hyper from the hype in non-linear text? In H. Bullinger & B. Shackel (Eds.), Human-computer interaction - Interact '87. (pp. 1107-1113). NY: North-Holland.

Kinzie, M.B. & Berdel, R.L. (1990). Design and use of hypermedia systems. ETR&D, 38 (3), 61-68.

Landow, G. (1989). Changing texts, changing readers: Hypertext in literary education, criticism, and scholarship in reorientations. In T. Morgan & B. Henricken (Eds.), Literary theory, pedagogy, and scholarship (pp. 128-173). Urbana: University of Illinois Press.

Landow, G. (1990). Popular fallacies about hypertext. In D.H. Jonassen & H. Mandl (Eds.), Designing hypermedia for learning (pp. 39-59). Berlin: Springer-Verlag.

Marchionini, G. (1988). Hypermedia and learning: Freedom and chaos. Educational Technology, 28(11), 8-12.

Mayer, R.E. (1984). Aids to text comprehension. Educational Psychologist, 19(1), 30-42.

Mayes, T., Kibby, M., & Anderson, T. (1990). Learning about learning from hypertext. In D.H. Jonassen & H. Mandl (Eds.), Designing hypermedia for learning (pp. 227-250). Berlin: Springer-Verlag.

McKeithen, K.B., Reitman, J.S., Rueter, H.H., & Hirtle, S.C. (1981). Knowledge organization and skill differences in computer programmers. Cognitive Psychology, 13, 301-325.

Meyer, B.J.F. (1975). The organization of prose and its effect on memory. Amsterdam: North-Holland.

Milheim, W.D. & Martin, B.L. (1991). Theoretical bases for the use of learner control: Three different perspectives. Journal of Computer-Based Instruction, 18(3), 99-105.

Naveh-Benjamin, M. and Lin, Y.G. (1991). Assessing students' organization of concepts: A manual for measuring course-specific knowledge structures. Ann Arbor, MI: NCRIPTAL.

Naveh-Benjamin, M., McKeachie, W.J., & Lin, Y.G. (1987). Two types of test-anxious students: Support for an information processing model. Journal of Educational Psychology, 79(2), 131-136.

Naveh-Benjamin, M., McKeachie, W.J., & Lin, Y.G. (1989). Use of the ordered-tree technique to assess students' initial knowledge and conceptual learning.

Teaching of Psychology, 16(4), 182-187.

Naveh-Benjamin, M., McKeachie, W.J., Lin, Y.G., & Tucker, D.G. (1986). Inferring students cognitive structures and their development using the "ordered tree" technique. Journal of Educational Psychology, 78(2), 130-140.

Oren, T. (1990). Cognitive load in hypermedia: Designing for the exploratory learner. In S. Ambron & K. Hooper (Eds.), Learning with interactive multimedia: Developing and using multimedia tools in education (pp. 125-136). Redmond, WA: Microsoft Press.

Phillips, T. L., Watson-Papelis, G., Cook, J., Ming, L, and Tiancheng, L. (1992). The effects of structure aids on level of learning and efficiency in an instructional hypermedia environment. Paper presented at the annual conference of the Association for Educational Communications and Technology (Washington, DC, February, 1992).

Reigeluth, C.M. & Stein, F.S. (1983). The elaboration theory of instruction. In C.M. Reigeluth (Ed.), Instructional design theories and models: An overview of their current status (pp. 335-382). Hillsdale, NJ: Erlbaum.

Reitman, J.S. & Rueter, H.H. (1980). Organization revealed by recall orders and confirmed by pauses. Cognitive Psychology, 12, 554-581.

Remde, J.R., Gomez, L.M. & Landauer, T.K. (1987). SuperBook: An automatic tool for information exploration - hypertext? Hypertext '87, pp. 175-187.

Roller, C.M. (1990). The interaction of knowledge and structure variables in the processing of expository prose. Reading Research Quarterly, 25(2), 79-89.

Romiszowski, A.J. (1990). The hypertext/hypermedia solution - but what exactly is the problèm? In D.H. Jonassen & H. Mandl (Eds.), Designing hypermedia for learning (pp. 321-354). Berlin: SpringerVerlag.

Shavelson, R.J. (1974). Methods of examining representations of a subject matter structure in students' memory. Journal of Research in Science Teaching, 11, 231-250.

Spilich, G.J., Vesonder, G.T., Chiesi, H.L., & Voss, J.F. (1979). Text processing of domain-related information for individuals with high and low domain knowledge. Journal of Verbal Learning and Verbal Behavior, 18, 275-290.

Spiro, R. J. & Jehng, J.C. (1990). Cognitive flexibility and hypertext: Theory and technology for the nonlinear and multidimensional traversal of complex subject matter. In D. Nix & R.J. Spiro (Eds.), Cognition, education, and multimedia: exploring ideas in high technology (pp. 163-205). Hillsdale, NJ: Erlbaum.

Spyridakis, J.H. (1989). Signaling effects: A review of the research -- Part I. Journal of Technical Writing and Communication, 19(3), 227-240.

Spyridakis, J.H. (1989). Signaling effects: Increased content retention and new answers -- Part II. Journal of Technical Writing and Communication, 19(4), 395-415.

Steinberg, E.R. (1977). Review of student control in computer-assisted instruction. Journal of Computer-Based Instruction, 3, 84-90.

Thro, M.P. (1978). Relationships between associative and content structure of physics concepts. Journal of Educational Psychology, 70, 971-978.

Tsai, C.J. (1989). Hypertext: Technology, applications, and research issues. Journal of Educational Technology Systems, 17(1), 3-14.

Whalley, P. (1990). Models of hypertext structure and learning. In D.H. Jonassen & H. Mandl (Eds.), Designing hypermedia for learning (pp. 61-67). Berlin: Springer-Verlag.

Wright, P. (1990). Hypertexts as an interface for learners: Some human factors issues. In D.H. Jonassen & H. Mandl (Eds.), Designing hypermedia for learning (pp. 169-184). Berlin. Springer-Verlag.