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# The Relevance of Hierarchies to Learning Biology From Hypertext

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Previous research on text-based learning has shown the relevance of hierarchical structures to the acquisition of complex concepts and the formation of knowledge structures. Because of the inflexible nature of traditional text, however, these studies have been limited to comparing participants learning with either hierarchical or linear presentations. As a consequence, our understanding of the importance of hierarchies to information processing is only relative to that of linear text. The purpose of this investigation is to move beyond that comparison, to explore more deeply the relevance of hierarchies to information processing. For this study, the traits that characterize a hierarchy were isolated and used in varying combinations to create 4 different organizations for a single body of information: hierarchical, clustered, unstructured, and linear. The creation of these structures was made possible by hypertext technology. Participants were each assigned to study one of these systems and were then asked to take cued-association, problem-solving, and factual-knowledge posttests. Results of these tests suggest that participants in all conditions created hierarchical representations as they worked and that those in the nonlinear conditions used this structure to guide their exploration of the material. They also suggest that an important function of hierarchies may be to define relations between concepts. Results are discussed in relation to current theories of learning, the construction of knowledge structures, and application to educational settings.

Quite a bit of evidence has converged on the fact that hierarchies are relevant to the way in which humans encode, store, and retrieve information. Hierarchical structures have shown to be important with reference to information acquisition (Bower, Clark, Lesgold, & Winzenz, 1969; Eylon & Reif, 1984; Kintsch & Keenan, 1974),

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conceptual structure (Chi, Hutchinson, & Robin, 1989; Kintsch & van Dijk, 1978; Mannes & Kintsch, 1987; Mayer, 1979; Shavelson, 1972, 1974; Thro, 1978), and expert performance and problem solving (Chase & Simon, 1973; Chi & Koeske, 1983; De Groot, 1965; Friendly, 1977; Hughes & Michton, 1977; Johnson, 1967). This investigation is concerned with understanding why hierarchical information structures have an effect on learning and conceptual structure. As the following literature review shows, hierarchies have been studied as an organizational feature of semantic memory networks and as tools for augmenting memory and conceptual structure. The underlying reason for hierarchies' effects are less well studied, however. Do hierarchies interact in some basic way with information processing, or do such structures simply provide some element that facilitates learning? This investigation asks what it is about hierarchies that makes them useful. Addressing this issue is of theoretical interest because it will allow a clearer picture to emerge of the way in which information structures effect information processing. It is also of practical concern because a better understanding of this interaction will guide the creation of instructional materials. In the particular case of educational hypertext, this information will allow designers to optimize system design to facilitate real learning rather than mere navigation and search from nonlinear information.

## THE RELEVANCE OF HIERARCHIES TO LEARNING

Hierarchies have been shown to be relevant to memory store by response time studies and studies of text-based learning, hypertext-based learning, and expertise. In their seminal study, Collins and Quillian (1969) proposed a model of memory store in which information was arranged in a roughly hierarchical network of nodes and links. Their model posited that information about a topic was stored in propositional units, with general information at the "top" of the hierarchy, and more specific information on "bottom." Access to stored memories occurred as activation spread up and down the tree structure until the object of the search was found. Collins and Quillian supported their model with evidence from a response time study. Using a sentence verification task, they were able to show that, the further up or down on the hierarchy, the longer it took to activate any particular node. For example, they were able to show that sentences like *a canary is an animal* took longer for participants to verify than *a canary is a bird*. They interpreted such results to mean that the entry for animal was further from canary than bird in the hierarchical network, as predicted.

Although Collins and Quillian (1969) never actually claimed that memory is ordered within a strict hierarchy (see also Collins & Loftus, 1975), their article was followed by a flood of research that was focused on refuting the idea that memory is structured in this way. Several researchers, for example, were able to show that people's perceptions of categories are more complex than a hierarchy could explain. In an often-cited study, Smith, Shoben, and Rips (1974) used different sentences in Collins & Quillian's sentence verification task to show that the structure of semantic memory was more complicated than the tidy arrangement that would be characterized by a hierarchy. In a strict hierarchy, verifying that both watermelon and apple are members of the fruit category, for example, should take an equivalent length of time. However, Smith et al. were able to show that sentences like "a watermelon is a fruit," took longer to verify than "an apple is a fruit." Rosch (1973, 1975) showed that some members of categories (like fruit) are more typical than others. She hypothesized that typical members contain more of the features that have been abstracted to create the category in the first place. A strictly hierarchical representation of concepts in memory can not capture such subtleties.

It was also shown that the categories implicit to hierarchies may not be easily defined. Sokal (1977) illustrated the fuzziness of concept boundaries. He asked experts to categorize imaginary insects and found that, although they tended to agree about category membership, the criteria used to decide on membership varied between individuals. There are often no clear rules on which people agree about category membership. Based on such evidence, McCloskey and Glucksberg (1978) concluded that stored human knowledge is organized by much more complex principles than a limited hierarchy could possibly express.

Despite such arguments, evidence about hierarchies has also emerged from a different sector of the literature. Rather than probing semantic networks with response time tasks, researchers began investigating the structure of mental representations for complex domains (i.e., *conceptual structure*) through other means. Working from this perspective, researchers have been able to illustrate the importance of hierarchies in children as well as adults. For example, Chi and Koeske (1983) conducted a case study of a 4-year-old's (extensive) knowledge of dinosaurs. They were able to map his mental representation of dinosaurs by engaging him in a series of recall tasks. They found that his cognitive structure was roughly hierarchical. These results concur with the observations of adult experts made earlier by others (Chase & Simon, 1973; Friendly, 1977; Johnson, 1967).

Chi et al. (1989) followed up on this study by exploring the relation between hierarchical mental structures and knowledge use. They studied children who they classified as either dinosaur experts or novices. They found that, unlike the novices, the experts had a hierarchically structured knowledge base for dinosaurs. They were also better able to generate causal explanations, use categorical reasoning, and induce attributes about novel dinosaurs. From this perspective, a hierarchically organized knowledge base is important to learning and memory.

Others were able to show that hierarchical information structures result in hierarchical conceptual structures and produce enhanced learning outcomes in adults. In a study of text-based learning, Eylon and Reif (1984) gave two groups of participants the same body of information about gravitational acceleration. One group was given a hierarchical organization and the other a linear organization. The researchers found that participants in the hierarchical condition were better able to solve problems related to the materials they studied than those in the linear condition. Furthermore, they reported that participants in the hierarchical condition represented the information they learned in hierarchical mental structures.

A more recent study of hypertext-based learning conducted by Dee-Lucas and Larkin (1995) found that a hierarchical advance organizer aided learners. Groups of participants read about a topic using either traditional text or a hypertext system containing the same content. The hypertext users were given advance organizers structured either alphabetically or hierarchically. When given a well-defined learning goal, the hypertext users working with a hierarchy outperformed the other participants on a variety of outcome measures.

In summary, the work of Collins and Quillian (1969) prompted a flurry of research on the hierarchical nature of knowledge structure. Although this body of literature converged on the conclusion that semantic networks are much more complicated than a strict hierarchy, other evidence has emerged that points to the fact that hierarchical structures are present in the mental representations of adults and children. It has also been shown that they distinguish the mental representations of experts and novices and promote recall and problem solving. The purpose of this investigation is to explore why hierarchies seem to have a positive effect on learning and concept acquisition. Addressing this issue is of theoretical interest because it will reveal how these complex information structures interact with information processing. It is also of practical concern because a better understanding of this interaction will allow designers to optimize hypertext system design. A great deal has been written on the topic of learner centered design (LCD) over the past few years (Soloway, Guzdial, & Hay, 1994). LCD is a philosophy of system design that rejects the notion of designing systems for mere usability in favor of their ability to promote learning. Within the context of LCD, a better understanding of any factor that facilitates learning, including hierarchies, is important to educational system design.

## WHAT IS THE REASON FOR THE EFFECT OF HIERARCHIES?

Thus far, I have established that hierarchies are important to knowledge store and use when measured in a variety of ways. The remainder of this introduction motivates the methodology of this study, which was conducted to explore the underlying reasons for the effect of hierarchies on learning. Because prior research has shown the benefit of hierarchies in relation to linear structures, one way to explore this issue is to specify the ways in which hierarchical and linear information structures are distinct and search among those differences for characteristics relevant to learning. This was the strategy taken in this study. To this end, hierarchies are dis-

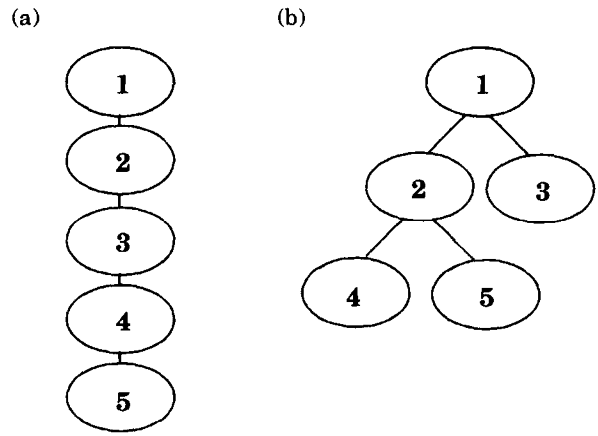


FIGURE 1 Illustration of the differences between linear structures (a) and hierarchies (b).

tinguished from linear text by three characteristics. Figure 1 illustrates these differences, which are identified and described in the following list.

1. *Two-dimensional levels and groupings.* Rather than appearing sequentially, as in Figure1a, a systematic, two-dimensional placement of nodes serves to create levels and identifiable groupings, such as Nodes 2, 4, and 5 in Figure 1b. These groupings are created by the existence of branches and levels within the structure.

2. *Multiple links between concepts.* A strict linear presentation has no more than two links per node, as each is connected only with those that directly precede and follow it. Even in a very simple hierarchy, such as in Figure 1b, any node may have links to multiple associates, as exemplified by Node 2.

3. *Links are conceptually defined.* This feature is an emergent property of those described previously. In a linear presentation, little or no information about the relations between linked nodes is provided by the structure. For example, the relation between Nodes 2 and 4 in Figure 1a is indistinguishable from that between 3 and 4. Node 4 may be a sibling of Node 3 and a subtype of Node 2. On the other hand, Node 4 may be a subtype of Node 3. There are many other types of hierarchical and nonhierarchical relations that may be denoted by any of the links in the linear structure (such as functional, causal, or temporal relations). The point is that the linear structure alone can not specify this information. Rather, the content of the structure must provide this information for the learner. In contrast, a hierarchy provides implicit information about the relations between nodes, regardless of the content. Even in the absence of any real content, as in the case of Figure 1b, for example, there is immediate and unmistakable recognition of the subordinate relation between Nodes 2 and 4.

The question addressed by this study is whether one of these three characteristics (or some combination of them) may contribute to conceptual structure and learning. This possibility was addressed by isolating these features and observing their relative effects on concept acquisition and problem solving.

## METHOD

### Design and Materials

As stated earlier, hierarchies have been compared only with linear structures in studies of text-based learning. As a result, the literature has not been able to separate the basic effects of hierarchies on learning from their effects relative to linear structures. This is a subtle but important distinction if the goal of understanding the reasons for the effects of hierarchies on learning is to be achieved. The focus on that particular comparison has been due, in part, to the difficulty in imposing other organizations on a body of text. With the aid of hypertext technology, however, this problem is easily solved. Before explaining how this technology was used to aid in this investigation, the concept of hypertext is first explained.

In its simplest form, hypertext allows large collections of text-based documents to be displayed on small, individual computers or as part of a networked system. *Link buttons* (programmed into individual documents) connect a document to others within the same system. The user moves from one document to another by "clicking" on buttons with a mouse. Perhaps the most striking aspect of the technology is the flexibility it offers programmers and users to interconnect conceptually related pieces of information. As a result, the presentation of information is flexible and nonlinear, as there are numerous avenues an interested user can explore within a single corpus. With minor alterations to the user interface, this flexibility also makes it easy to impose a virtually unlimited number of structures on a body of information. Thus, the malleability of hypertext structure provides a means of working around the inherent limitations of traditional text. In fact, Shapiro (1998) showed that hypertext can be comparable to linear presentations of text for presenting participants with experimental stimuli in a study of text-based learning. The following section describes the systems created for this study.

*System design.* Because of the nature of the study, it was important that participants were unfamiliar with the information to be presented before they began. For this reason, an imaginary world named Cyrus was invented. Most of the system's graphics were borrowed from Dixon's (1981) *After Man: A Zoology of the Future*, which proposed a vision of the Earth's wildlife 50 million years from now, long after Dixon's anticipated extinction of mankind. The many illustrations of these creatures are extremely detailed and believable. Information about the biology and ecosystems of Cyrus was developed by the experimenter and digitized along with the graphics to be used as stimuli. Two expert biologists and one ecologist were consulted about the realism and plausibility of the materials during development. All the materials received approval by the experts before being incorporated into the final stimuli.

The four systems created for this study were developed with HyperCard 2.1 on a Macintosh IIsi, equipped with a 13-in. monitor. In each of the three hypertext systems, individual nodes or documents contained illustrations and factual information about individual topics. Electronic links allowed participants to travel between documents. The linear condition also had nodes but no links connecting them; it worked like a book. Each of the 33 documents of the four systems occupied a single "card" or screen. Examples of system documents are provided in Figures 2, 3, 4, and 5 and each system is described in detail in the following.

The hierarchical system incorporated electronic links that were designed to move the user between nodes, impose a hierarchical structure on the information, and point to relations between topics. Information about habitats, natural predators, food sources, and so forth were linked to appropriate nodes within the "tree" structure. Care was taken to give users the sense of being in a hierarchically arranged network of nodes and links.

As seen in Figure 2, the identity of users' current branch of the hierarchy was made explicit by the bar above the darkly shaded region on the lower right-hand portion of each card. In this case, the user is on the Herding Animals branch. Users always knew their current level in the hierarchy by looking at the `Current Level` field located within the darkly shaded region. In the case of Figure 2, users on the `Common Rabbuck` document could see that they were on the third level of the `Herding Animals` branch (`Herding Animals` was on the second level and a system "home page" was on the first). Documents that were superordinate to the current document were identified by `up-arrow` link buttons in the darkened portion of the screen. Likewise, subordinate documents were identified by `down-arrow` link buttons.

Users were also able to move laterally to a new topic on their current level. There were two types of lateral moves. Users could choose to move laterally to but remain within the current animal family. Such a move took the user to a "sister" document by remaining on the current branch of the hierarchy. Such links were located in the medium-shaded portion of the screen. In this example, another type of herder, the "helmet horn" was made accessible in this section. Participants could also move laterally to a "cousin" node. Such a move took the user across families to a new branch of the hierarchy. These links were found in the lightly shaded section of the screen. In this example, moving from `common rabbuck` to the `night stalker` or `forest` would be considered across-families lateral moves. Knowledge of superordinate and subordinate relations as well as level and

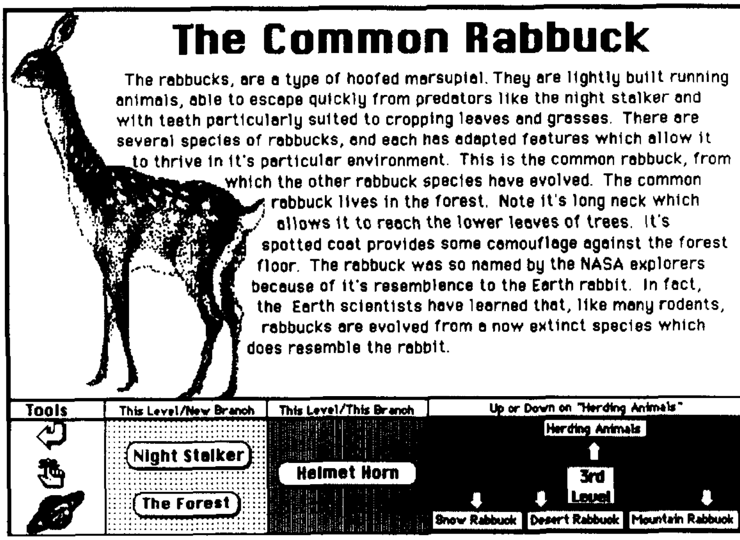


FIGURE 2 Sample card from the hierarchical system. The hierarchical system is equipped with multiple links between topics, navigation tools, and aids to define superordinate/subordinate nodes, node levels, and branch identities.

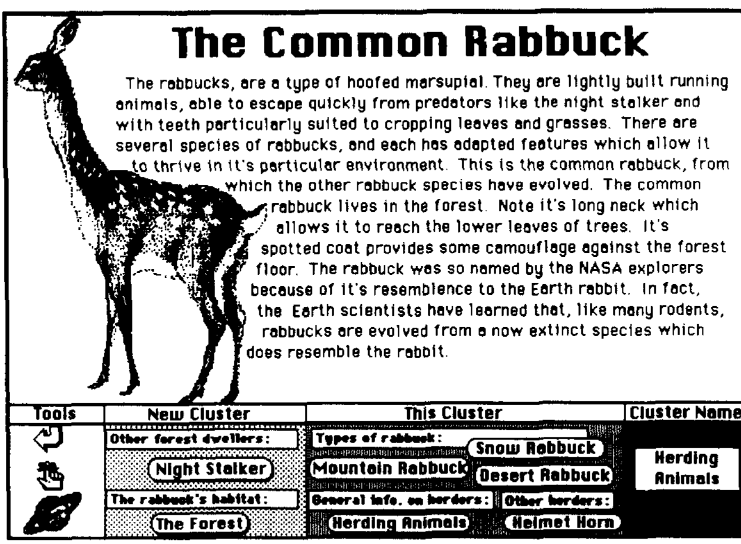


FIGURE 3 Sample card from the clustered system. The clustered system is equipped with multiple defined links between topics, navigation tools, and aids to define cluster membership.

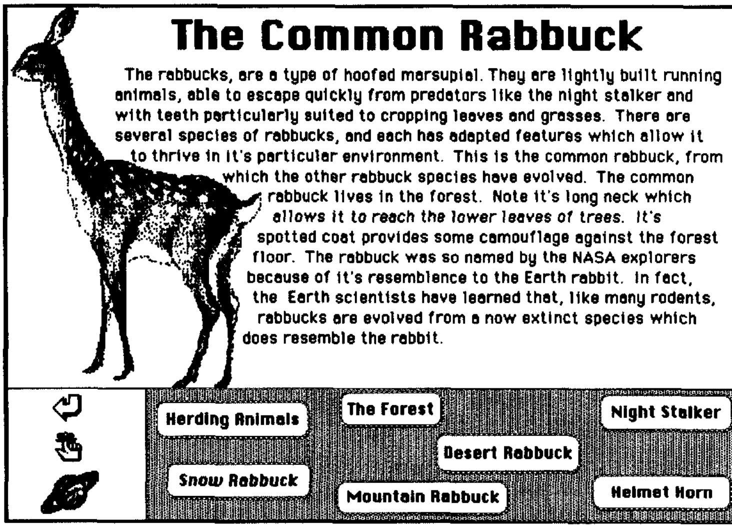


FIGURE 4 Sample card from the unstructured system. The unstructured system is equipped with navigation tools and contains multiple links between topics.

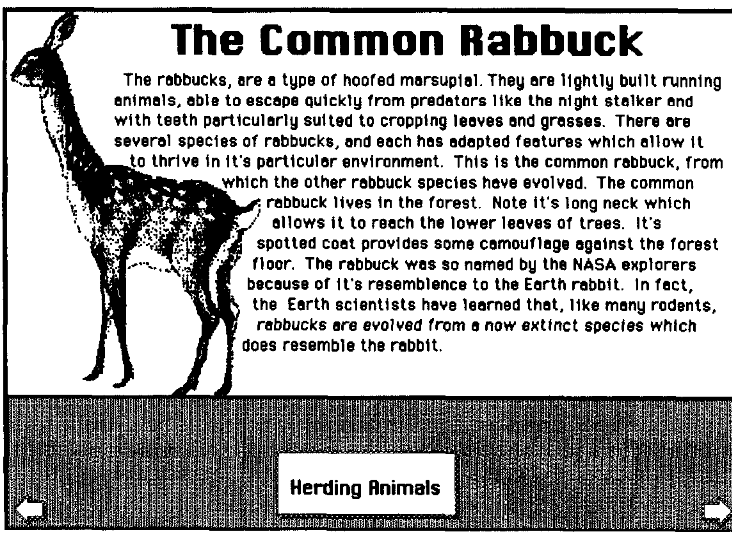


FIGURE 5 Sample card from the linear system. The linear system is organized by chapter and equipped only with next and previous card buttons.

branch membership, provided users with an understanding of the relations between linked documents. This knowledge also provided a means or orienting oneself in the system.

The question of orientation is important because the problem known as "getting lost in hyperspace" is nontrivial. Indeed, the cognitive load of finding one's way and staying oriented in a hypertext system is a well-known problem, one that has been shown to detract from the learning experience (Hammond & Allinson, 1988, 1989; Laurel, Oren, & Don, 1990; Marshall & Irish, 1989; Nielsen, 1989, 1990; Parunak, 1989; Zellweger, 1989). To control for such difficulties, other orienting devices, located in the lower left-hand portion of each card, were programmed into the system. The `back` button, represented by the curved arrow icon, allowed users to retrace their path through the system. Each time the button was clicked, the user was moved to the document viewed prior to the current document. Clicking the `String Finger` button brought up a window that offered the name and level of the document viewed prior to the current document. The `Cyrus` button carried users to the place from which they started, the `Introduction to Cyrus` document, located at the top of the hierarchy. This allowed a disoriented user to get out of unfamiliar territory and get reoriented. With only 33 nodes in the system, however, the network was fairly tractable to users. In fact, none of those who participated in the study reported trouble remaining oriented as they maneuvered through the information space.

The clustered system contained links and nodes identical to those of the hierarchical system. However, it presented the information in nonhierarchical clusters of animals, habitats, predators, and so on. The clusters corresponded to the major branches in the hierarchical system. As seen in Figure 3, participants were always aware of the identity of their current cluster from the `cluster field` in the lower right-hand portion of the screen. In the case of the example in Figure 3, the Common Rabbuck document was a member of the Herding Animals cluster.

Participants in this condition were able to move to documents either within their current cluster (by clicking buttons in the medium-shaded portion of the screen) or a new cluster (by using buttons in the lightly shaded portion of the screen). Although a hierarchical arrangement provides a great deal of information about topic relations, knowledge of cluster membership provided minimal information about the relations between documents. However, participants in the clustered condition were actually provided with slightly more information about document relations than the hierarchical group because the link buttons were all labeled. For example, whereas participants in the hierarchical condition knew that the `Night Stalker` document was related in some way to the common rabbuck document (via a lateral link), those in the clustered condition were aware that the night stalker was another forest dweller, and therefore a member of the common rabbuck's ecosystem. The navigating tools available in the hierarchical system were also available in the clustered system. The clustered system's string finger button, however, offered information about cluster identity rather than document level.

TABLE 1
Characteristic Traits of Hierarchies Explicitly Presented by the Systems Developed for This Study

| | *System Structure* | | | |
|---|---|---|---|---|
| *Hierarchy Traits* | *Hierarchical* | *Clustered* | *Unstructured* | *Linear* |
| Multiple links between topics | ✓ | ✓ | ✓ | |
| Defined topic relations | ✓ | ✓+ | | |
| (Two-dimensional) levels and groupings | ✓ | | | |

*Note.* The plus sign refers to the more complete and explicit definitions provided by that system as compared to the hierarchical system.

The unstructured system contained the same links and nodes as the hierarchical and clustered systems. As shown in Figure 4, however, this system provided no organizing features and appeared to users as an unstructured network of nodes and links. The orienting tools provided in the other linked systems were available to users, but the string finger tool only provided the name of the last card visited.

The linear system contained the same documents as the other three, but presented them within a linear structure. It appeared as a digitized book and contained no links between documents, with the exception, of course, of those nodes that preceded or followed their neighbors. The book was divided into chapters that corresponded to both the major branches in the hierarchical system and the clusters in the clustered system. A field with the chapter name appeared at the bottom of each card to keep users oriented. They served the same purpose as the short titles found at the top of book chapters and were not interactive. A sample card is provided in Figure 5.

No overview maps were provided for any of the conditions so that the well-documented effects of advance organizers could not confound the present results (Dee-Lucas & Larkin, 1995; Mayer, 1979). As shown in Table 1, each condition was designed to explicitly present one or more of the hierarchy traits described earlier. Obviously, the hierarchical system contained all of the traits of a hierarchy. The clustered system contained multiple links between topics and the relations represented by those links were explicitly defined. There is a "√+" entered under the clustered group's column for the `Defined Topic Relations` entry because there was actually slightly more information about topic relations in that condition than in the hierarchical condition. However, the clustered system did not offer the same levels and groupings as a hierarchy. With some work, it would be possible for participants to create a hierarchy from the grouping information and label names available in that condition. Indeed, the aim of this investigation is to explore whether learners are biased toward forming such a representation as they work. Nevertheless, a hierarchy was not explicitly presented in this condition, so no check appears in that box for the clustered system. The unstructured system offered multiple links between topics but offered no explicit information about the relations between them and did not impose an ordered arrangement of levels and groupings on the information. Finally, the linear system was a control condition and, obviously, contained none of the traits that distinguish it from a hierarchy.

These systems have made it possible to compare the effects of a number of structures on concept acquisition. Furthermore, they made it possible to isolate the components identified as distinctive of hierarchies so that their effects on concept acquisition could be examined. If the unique collection of a hierarchy's elements is responsible for the improved performance of participants, as reported in other studies, the hierarchical group in this study should outperform those in the remaining conditions on the problem-solving posttest. Also, the associations they report between topics during the cued-association task should mirror that of the system. However, if the power behind a hierarchy lies in its ability to impart information about topic relations, the clustered group should perform comparably to the hierarchical group on all measures. After all, the clustered system contains the same nodes and links and actually provided slightly more information about intertopic relations. Its main distinction from the hierarchical system was that it provided clusters as the organizing feature rather than levels and branches. Finally, if simply pointing out the existence of relations between topics is the matter of importance, the three hypertext groups should perform comparably to one another but should perform differently from the linear group.

## Participants

Thirty-two undergraduate students were paid for their participation in the study. All were native speakers of English and reported no diagnosed learning disability. Each was randomly assigned to one of the four systems developed for the study. Through random assignment, the few biology majors who participated were evenly distributed among conditions (0, 1, 2, and 1 in the hierarchical, clustered, unstructured, and linear conditions, respectively).

## Learning Phase and Posttesting

Participants were instructed about using the mouse to click on buttons that would allow them to travel between documents. They were told of their respective systems' organization and how best to take advantage of it. All participants were asked to work through the system and learn as much as possible about its content. They were told to work at their own pace, to take as long as they required, and that they would be asked to complete a variety of posttests when they were through. Participants worked between 45 and 60 min. A computer program logged participants' navigation behavior as they worked (i.e., which documents they visited, how long they spent on each topic, which buttons they clicked, etc.).

On completing the learning phase of the study, all participants were asked to take factual-knowledge, cued-association, inference problem-solving, and information-mapping posttests. They were allowed to work as long as they needed to complete their tasks, although most finished within 30 to 45 min. The posttests are described in the following sections.

*Factual knowledge test.* This short-answer test contained 10 questions designed to probe for knowledge of simple facts found on random cards throughout the system. Examples of these questions are: What characterizes the main staple of the heavy-billed whistler's diet? Where do the auk lay their eggs? Aside from their inability to produce heat, what characterizes all reptiles on Cyrus?

*Cued-association test.* A goal of this research was to determine whether hierarchical structures have a unique effect on the organization of stored associations. One problem researchers interested in conceptual structure have always faced is how to procure an accurate rendering of participants' representations. Indeed, it is not clear that any known methods are satisfactory (however, see Chi et al., 1989; Chi & Koeske, 1983). In fact, it is not clear that the structure of stored associations is either static or stable. Coleman (1993) noted that obtaining an accurate picture of an individual's mental representations is clearly problematic. She suggested that the most one can hope to obtain is an impression of one possible structure at a given moment. In fact, Spiro and colleagues (Feltovich, Spiro, & Coulson, 1989; Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987) argued that the lack of static structure, a concept they call *cognitive flexibility*, is a trademark of deep understanding . Because capturing the overall structure of individuals' acquired knowledge is problematic, a more conservative approach was taken in this study. Participants' acquired associations were probed to determine whether they were related to those present in the hypertext systems. The cued-association task was presented as a means of gathering that information.

This test was given before the others to prevent associations between topics from being formed after the learning phase. A HyperCard program was written to present the task. Participants read a set of instructions on the computer that explained which topic names from the system would appear on the computer screen. Their task was to use provided response sheets to write as many as three system topics that immediately came to mind. After working on a practice item, participants clicked a button to begin and the first topic name appeared on the screen. When they were through entering their associations for that item on the answer sheet, they clicked another button to see the next topic. This procedure was repeated until all 32 items on the test were completed. When participants completed the cued-association task, their computers were turned off and they were given the remaining posttests.

*Information mapping.* In another attempt to get some reading of how learners in the study organized the information they learned, each was asked to draw a picture of his or her representation of the material. Specifically, participants were given the following instructions:

> How do you see the organization of the topics in the system? Draw a picture which represents how *you* perceive the overall structure of the system topics. Your conceptualization of the system's organization may or may not be the same as the structure presented by the computer. You can be specific about the placement of the topics in your structure by using topic labels, or you can be general and sketch the basic layout.

Rather than looking at connections between specific topics as in the cued-association task, the information-mapping task was designed as a (crude) way of obtaining some indication of the "shape" of participants' conceptualizations.

*Problem-solving test.* The problem-solving posttest contained 12 items that were designed to assess participants' ability to use their knowledge of facts from the system to solve novel problems. For example, one item asked how an unusual dry spell would affect the fin lizard's food source. Participants who read the fin lizard document knew that the reptile eats long-plumed quail eggs. The long-plumed quail document, in turn, stated that these birds do not lay eggs during dry periods. Knowledge of these facts should allow the participant to infer that an unusual dry spell would reduce the availability of food for the fin lizard. Examples of other questions are: How are the shurrack affected when the grasses on the high elevations of the mountains grow thin? Why would the Arctic sabre bear be likely to gather along the shoreline in autumn? How would a needle-nose whistler be affected by the loss of its head feathers?

Three types of questions comprised the problem-solving test. To correctly answer intertext/linked items, knowledge of facts from two documents that were connected by electronic links in the three hypertext systems was required. Intertext/unlinked items were designed to test the individual's ability to join information from two documents that were not directly linked in any of the system conditions. To correctly answer intratext items, it was necessary that two facts from a single document be related to arrive at a novel inference. The purpose of including different question types was to examine whether the presence of an explicit pointer to a relation between two topics had any impact on participants' ability to make that connection either in memory store or during use. The questions were all presented in random order.

## RESULTS AND DISCUSSION

### Factual Knowledge

There was no difference between system groups' performance on the factual knowledge test, $F(3, 28) = .37, p > .05$. The mean percentage correct for the hierarchical, clustered, unstructured, and linear system groups was 66.25, 71.25, 68.75, and 76.25, respectively (*SDs* were 10.61, 31.37, 18.08, and 11.88). All structures were equivalent mediums for imparting the declarative, factual information contained in each node. This result makes sense because the information contained on each document was invariant across conditions; the treatment conditions differed only in the way in which the documents were interconnected. The lack of any reliable difference between groups on this measure is important with references to the results reported later. Specifically, any subsequent significant effects cannot be attributed to lack of familiarity with the explicit information presented by each document on the part of any one group.

### Cued Association

As illustrated in Figure 6, there was a significant effect of system structure on the total number of associations reported by learners, $F(3, 27) = 4.67, p < .01$. Post hoc analyses using the Fisher PLSD reveal that the hierarchical, clustered, and unstructured groups each reported a significantly higher number of associations than the linear group, PLSD = 19.08, $p < .05$; PLSD = 18.44, $p < .05$; and PLSD = 18.44, $p < .05$, respectively, but their scores did not differ from one another.

These results suggest that learners who worked with any of the hypertext systems, not just the hierarchical system, gained more well-integrated representations for the material they studied. Do learners' associations mirror those presented by the stimulus materials? To answer that question, each learner's response to each cued-association item was categorized. Each response to a cue is called a *cue associate.* An associate that was connected to a cue topic through a link button in the three hypertext systems was categorized as a *link associate*. An associate that was not connected to a cue topic through a link button but whose relation to the cue was discussed in the text was categorized as a *text associate*. Categorizing participants' responses in this way made it possible to determine whether the associations participants reported during the cued-association task were derived from the links, and hence from the system structure.

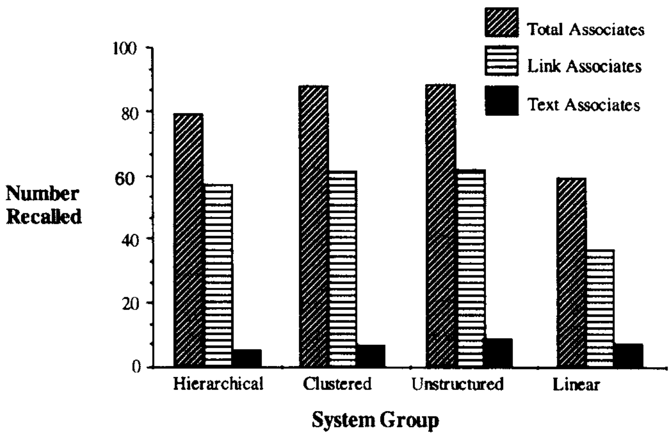


FIGURE 6 Mean number of total associates, link associates, and text associates reported by each group during the cued-association task.

The presence of links in the systems did, in fact, have a strong effect on the information participants stored in memory. As illustrated in Figure 6, an analysis of variance (ANOVA) revealed an effect of system structure on the number of reported link associates, $F(3, 27) = 3.75, p < .05$. Post hoc analyses show that the hierarchical, clustered, and unstructured groups all reported more associations that were imparted by the link structure than did the linear group, PLSD = 18.21, $p < .05$; PLSD = 17.59, $p < .05$; and PLSD = 17.59, $p < .05$, respectively. There were no reliable differences among the three hypertext groups' scores. The hypertext groups made more intertext associations than did the linear group. Obviously, the control group, the linear learners, had none of the link relations pointed out to them as they studied. This result indicates that a nonlinear network of information, regardless of whether it is hierarchically structured, serves to make salient the relations between nodes that are not otherwise likely to be acknowledged.

A question raised by these data is whether the hypertext groups acquired their link associations at the expense of information contained in the text. To address that concern, the mean number of text associates reported by learners in each of the system groups was also compared. As shown in Figure 6, there was no significant difference between system groups on this measure, $F(3, 27) = 1.35, p > .05$. Because all hypertext groups reported as many text associates as those in the linear condition, it is clear that those in the hypertext groups were not encoding information about link relations at the expense of node information, but in addition to it; they learned more.

It is possible, however, that these results are due to a simple repetition effect. In addition to the ability to move directly between related documents, the link buttons furnished all three hypertext groups with the names of related system topics each

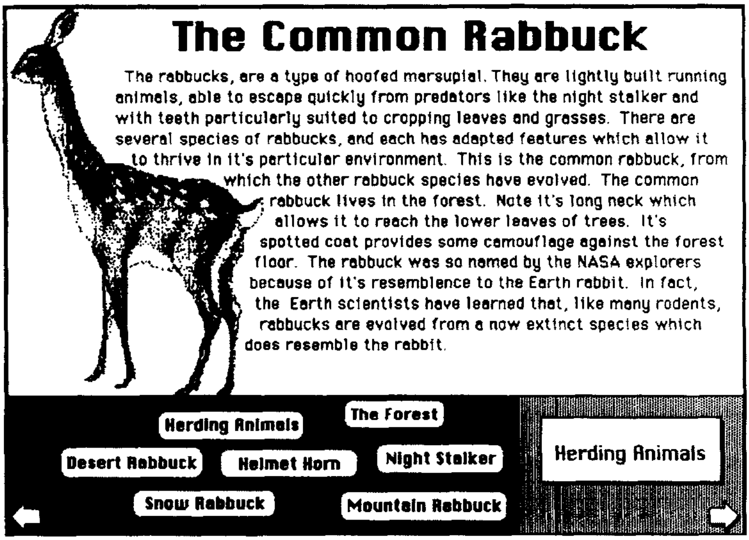


FIGURE 7 Sample card from the labeled linear system developed as a control condition for this study.

time they turned to a new document (see Figures 2, 3, 4, & 5). Because the linear group was not exposed to repeated associations between topics, the possibility exists that the significant effects of system condition are due to repeated exposure to the pairing of topics rather than moving through a highly integrated web of information, as suggested earlier. To test this hypothesis, another control condition was created. A separate group of 8 participants took part in the same procedure as those in the original study. These participants were advertised for in the same manner as the original pool and were compensated in the same manner. However, these participants worked with a hybrid of the linear and unstructured systems. As shown in Figure 7, the labeled linear system was identical to the linear system with the exception of the placement of topic labels on the lower left area of each document. These labels looked identical to the link buttons in the unstructured system, but they were inactive; users were unable to use those labels to move through the system. However, they were able to examine the same link labels as those in the three hypertext systems and were explicitly encouraged to do so. Afterward, they were given the cued-association test.

Participants in the labeled linear condition performed comparably to those in the linear condition. The labeled linear group reported a mean of 6.75 link associates ($SD = 7.31$), which is actually lower than the linear group's score. With the addition of the second control group, the analysis is still significant, $F(4, 35) = 6.40$, $p < .001$. The labeled linear group performed comparably to the linear group, PLSD

= 10.59, $p > .05$, but differed from all other groups, PLSD = 10.59, $p < .05$, in all cases. Likewise, the addition of the new control group affected no change in the overall outcome of the text associate results reported earlier. There was still no effect of system condition on the mean number of text associates reported by each group, $F(4, 35) = 2.48$, $p > .05$. The mean of 4.0 text associates ($SD = 2.67$) reported by the labeled linear group may be compared with those of the groups in the main study in Figure 6.

In summary, the labeled linear group performed equivalently to the linear group in all analyses. It also mirrored the linear group with respect to its performance relative to the three hypertext groups. In short, the results reported for the main study cannot be attributed to a repetition effect stemming from exposure to mere link labels. Rather, working with a multiple-linked body of information aided participants in gaining knowledge of the connections between ideas, regardless of whether the structure was hierarchical.

## Information Mapping

The maps that participants were asked to draw were grouped into four categories: hierarchical, clustered, combination, or undetermined. Those classified as hierarchical were characterized by levels of topics embedded in subordinate relations. Those characterized as clusters contained groups of topics related by some common theme with no hint of subordinate relations between items. Those characterized as a combination represented the material in both ways, generally by providing more than one drawing or a written explanation. Those that fell into none of these categories and did not reveal any clear criteria for their generation were categorized as undetermined.

As revealed in Table 2, chi-square analysis revealed a significant bias toward a hierarchical configuration by all groups, $\chi^2 = 17.31$, $p < .05$. Although the clustered group did have a greater number of clustered and combination maps than the other groups, the majority of participants even in that condition represented the material within a hierarchy.[1]

## Problem Solving

Overall, the four groups performed comparably on the problem-solving task, $F(3, 31) = .3$, $p > .05$. The mean scores of the hierarchical, clustered, unstructured, and

[1]The reader is cautioned not to make too much of the information-mapping posttest. This is a very crude measure of participants' understanding and, at best, provides only a snapshot of their conceptualizations at one moment in time.

TABLE 2
Percentage of Participants in Each System Condition Who Created Maps That Were Categorized as Either Hierarchical, Clustered, Combination, or Undetermined

| | *System Structure* | | | |
|---|---|---|---|---|
| *Map Type* | *Hierarchical* | *Clustered* | *Unstructured* | *Linear* |
| Hierarchical | 87.5 | 50 | 62.5 | 75 |
| Clustered | 0 | 37.5 | 0 | 0 |
| Combination | 12.5 | 12.5 | 0 | 0 |
| Undetermined | 0 | 0 | 37.5 | 25 |

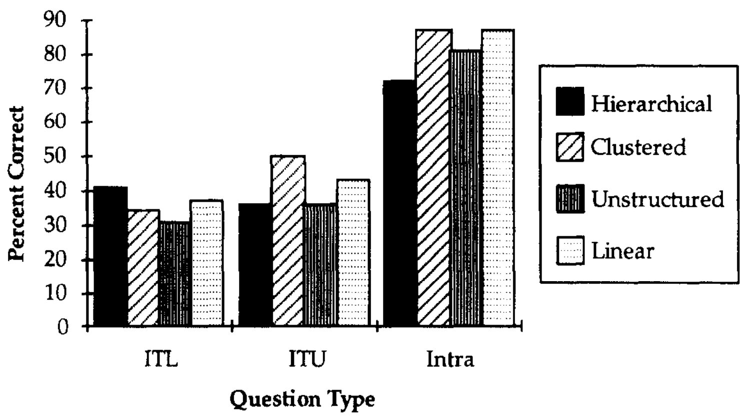


FIGURE 8 System groups' mean percentage correct on the intertext (ITL), intertext/unlinked (ITU), and intratext (Intra) problem-solving questions.

linear groups were 50.00, 54.13, 49.88, and 56.38, respectively. (*SDs* were 23.92, 25.52, 16.01, and 14.74.) However, there were three types of problems on the test: intertext/linked, intertext/unlinked, and intratext (described previously). Figure 8 illustrates that, although there was no significant interaction between system type and question type, $F(6, 84) = .34, p > .05$, all groups performed significantly higher on the intratext items than on any of the intertext items, $F(2, 93) = 25.24, p < .0001$. All of the groups' mean scores were in the B/C-range for the intratext items (they scored between 71% and 81% correct), but they all performed more poorly on both the intertext/linked and intertext/unlinked items.

It makes sense that participants would do poorly on the intertext/unlinked items. Without explicit information about the relation between two topics, participants would have little means to relate the information about those topics in memory. The reason for participants' poor performance on the intertext/linked problems may be related to their navigation paths. In studies that have used text to impose a hierarchical structure on a body of information, participants had no choice in their exposure to associations between ideas. Regardless of how the ideas within the text are organized, the linear nature of text necessitates a single order in which words must be read. Within a hypertext system, however, the order in which participants studied the documents was flexible, as they had the freedom to choose the links that were used. Not only was it possible for participants to skip links, it would have been almost impossible not to. If a participant did not actually use a particular button to move between two documents, why would the presence of that link augment later problem-solving performance? The question of interest, then, is whether participants in the three linked conditions moved directly between the documents concerning each of the intertext/linked items. For example, one item on the problem-solving test concerned the fin lizard and long-plumed quail. Did individual participants use the link connecting those two documents?

The navigation logs helped to provide this information. These data were then correlated with individuals' performance on each of the intertext/linked questions. Obviously, this analysis could not be performed on the linear group's data, as there were no links between items in that system. As illustrated in Figure 9, a chi-square test revealed no reliable relation between crossing directly between two documents in the hierarchical system and correctly solving a novel problem involving those documents, $\chi^2 = .26$, $p > .05$. Figure 10 shows that the same was true for participants in the unstructured condition, $\chi^2 = .56$, $p > .05$. For the clustered group, shown in Figure 11, there was a significant relation between moving directly between two topics and solving a novel problem concerning those topics, $\chi^2 = 4.53$, $p < .05$.

Why did crossing links in the clustered system improve problem-solving ability? The clustered and hierarchical systems differed in that (a) the hierarchical system was structured around levels and branches, and (b) the clustered condition

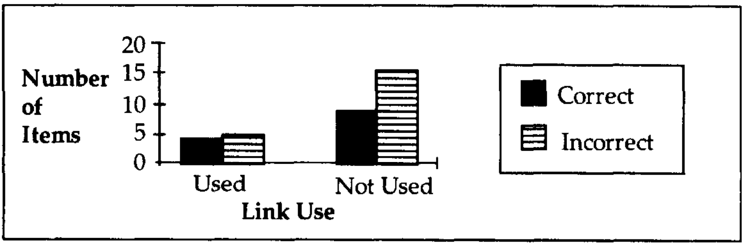


FIGURE 9 Illustrations comparing which links were used with performance on the corresponding problem-solving questions for the hierarchical system group. Chi-square analyses reveal significant results only for the clustered group (see Figure 11).

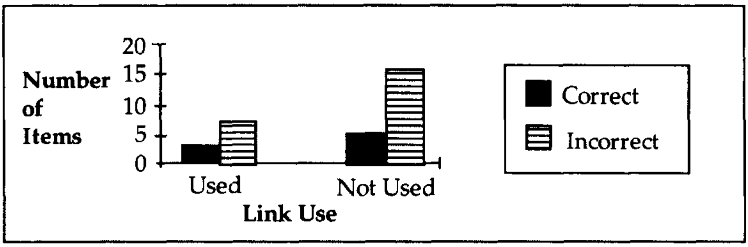


FIGURE 10 Illustrations comparing which links were used with performance on the corresponding problem-solving questions for the unstructured system group. Chi-square analyses reveal significant results only for the clustered group (see Figure 11).

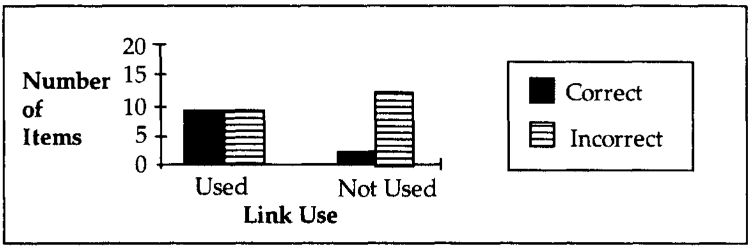


FIGURE 11 Illustrations comparing which links were used with performance on the corresponding problem-solving questions for the clustered system group. Chi-square analyses reveal significant results only for this group.

offered more explicit information about link relations. It is unlikely that the levels and branches would actually degrade performance, as the opposite effect has been widely shown (see the discussion in the introduction of this article). The more likely source of the effect is the clustered system's explicit information, which may have helped participants better understand the link relations. This explanation is supported by the fact that the difference between the clustered and unstructured conditions was the presence of definitions for topic relations. The data presented here indicate that attending to clear relations between ideas while studying aided participants in solving novel problems. Those without such overt information benefitted less from link use.

## Navigation Trails

There were no differences between groups with respect to the overall length of time spent learning, $F(3, 31) = .97, p > .05$. The means are provided in Table 3.

TABLE 3
Mean Length of Time Spent Learning, the Number of Vertical, Within Family Lateral, and Across Family Lateral Moves Made by Participants, and the Difference Between Across- and Within-Branch Lateral Moves (and Standard Deviations) in Each of the System Conditions

| | *System Structure* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Hierarchical* | | *Clustered* | | *Unstructured* | | *Linear* | |
| *Navigation Measure* | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| Minutes spent learning | 33.32 | 4.46 | 30.13 | 5.61 | 32.74 | 5.78 | 29.39 | 6.22 |
| No. of vertical moves | 33.75 | 15.56 | 34.75 | 21.63 | 31.75 | 15.06 | — | — |
| No. of across family lateral moves | 10.13 | 9.69 | 17.13 | 14.99 | 9.63 | 6.14 | — | — |
| No. of within family lateral moves | 22.75 | 8.12 | 19.00 | 6.95 | 21.50 | 12.18 | — | — |
| Difference of scores (across minus within) | 12.63 | 8.68 | 1.88 | 16.81 | 11.88 | 14.94 | — | — |

Because the question of interest is whether participants are influenced by a hierarchical structure in their learning and behavior, the primary analysis of interest is whether participants in the clustered and unstructured conditions moved through the system differently than the hierarchical participants. (Obviously, this comparison can not be made for the linear group.) To make this comparison, each movement made by each participant within the system was categorized in several ways. First, the number of vertical moves with reference to the hierarchical structure was categorized. Moving from `Common Rabbuck` to `Snow Rabbuck`, for example, was categorized as a vertical move. An ANOVA revealed no significant difference between groups with regard to the number of vertical moves, $F(2, 21) = .06$, $p > .05$. The means are presented in Table 3.

Lateral moves were subcategorized as either `within family` or `across families`. Within family lateral moves were those that kept the user on a single branch of the hierarchy, as in moving from `Snow Rabbuck` to `Desert Rabbuck`. Moving from `Common Rabbuck` to `Night Stalker`, however, was categorized as across families because the move took the user from the current branch to a new one (while keeping the user on the same level). There are no significant differences between groups with respect to the number of within-family lateral moves, $F(2, 21) = .33$, $p > .05$. The same is true for the number of across-family lateral moves, $F(2, 21) = 1.19$, $p > .05$. In addition, when difference scores (which indicate whether there was a greater tendency to use one type of move over the other) are calculated between the within- and across-family lateral moves, the comparison between the three groups is nonsignificant, $F(2, 21) = 1.49$, $p > .05$. Thus, there is no indication from the analyses of the navigation logs that there is any meaningful difference between groups' respective navigation behaviors.[2]

## GENERAL DISCUSSION

Previous studies have shown superior learning after exposure to hierarchical information structures. The purpose of this investigation was to determine whether such results reflect a sensitivity to hierarchies or to some characteristic they embody. Toward this end, three defining features of hierarchies were isolated: multiple links between concepts, two-dimensional/tiered groupings, and defined link relations. The study's results, summarized in Figure 12, are discussed with reference to these features.

All three multiply linked hypertext structures presented the same relations between system topics and the cued-association task revealed no differences between participant groups' stored associations. The only group to differ on this measure was the linear group, the only one that did not use the system's electronic links. As such, all of their associations had to be self-generated, whereas those of the other groups were guided. It is the case, then, that each hypertext structure was successful in imparting awareness of multiple relations between ideas. Although this was evident in measures of conceptual structure, there was no apparent effect on the learning outcome. Specifically, the linear group did not differ from the hypertext groups on the problem-solving or factual posttests. It does not appear, then, that the ability of hierarchies to point to multiple relations between ideas is central to their influence on learning outcomes.

Because all groups performed comparably on the posttest measures of learning and only the hierarchical group was exposed to the tiered groupings, it is tempting to conclude that this aspect of their structure is also irrelevant to the learning outcome. However, the navigation data indicate that participants in the three linked groups used the same general search pattern. In particular, they tended to explore the same number of hierarchical relations (as evidenced by the number of vertical links they followed). In addition, once on a level, they all tended to explore the same number of sibling relations within a family. The navigation results indicate that participants were actively creating hierarchies to guide their searches. Moreover, many participants drew hierarchical diagrams when asked to map the sys-

[2]Although the analysis of variance was nonsignificant, the clustered group's difference score was much lower than that of the other two groups. The nonsignificant result apparently stems from the remarkably high standard deviation for this group. This point indicates large individual differences among participants in this condition that may warrant future study.

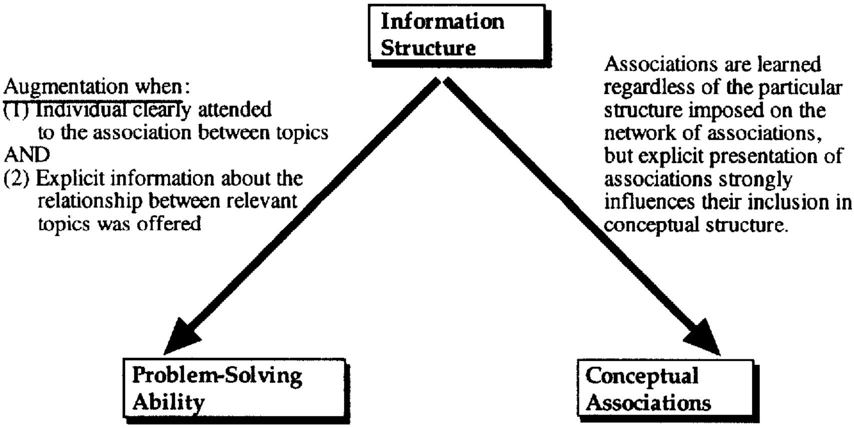


FIGURE 12 Illustration of the relations between results reported in this study.

tem. The tiers and groupings of a hierarchy, then, is evidenced to have been of some importance to participants.

The relevance of the tiers and groupings may not be due to the structure itself, however, but to the semantic relations they denote, the third characteristic of hierarchies. This point is supported by the positive association between the clustered system's link definitions and the learning outcome. Participants in that condition showed some advantage in solving problems when this explicit information was attended to (as evidenced by their use of a link). In contrast, neither the hierarchical nor unstructured groups showed a relation between problem-solving ability and relevant link use. This outcome suggests that attending to the more explicit relations between ideas was related to performance on the problem-solving test.

This finding may explain participants' tendency to seek out hierarchies as they worked. Because participants across groups seemed to be generating hierarchical representations for the material and using that knowledge to navigate the system, it is necessarily the case that they were aware of subordinate relations between animals. Coupled with the correlation between the clustered group's link use and problem-solving ability, this evidence supports the conclusion that participants created hierarchies as they worked in a quest to uncover meaning rather than mere structure. In other words, the hierarchical tiers and groupings that participants apparently sought out as they worked were important because they provided semantic information. The present results provide no indication that the tiered structure itself was important to the learning outcome. I conclude, then, that the relevance of hierarchies to learning and conceptual structure is due to the semantic relations they define between concepts.

This interpretation is supported by the construction integration model of text processing (Kintsch, 1988). This model is based on the idea that previously encountered information is used to anchor new information. When a sentence of text is read, its propositions are stored in short-term memory. When the next sentence's propositions are read, short-term memory is searched to see if the new propositions match. If they do, they may be integrated. If not, a *reinstatement search* is undertaken. That is, long-term memory is searched for propositions that can be matched with the new ones. If this is unsuccessful, the learner must create a separate structure for the incoming propositions. Although the learner may then make inferences to aid in locating relevant prior memory structures with which to interrelate the new structure, that does not always happen. The outcome is more sparsely connected mental representations and weaker understanding. In other words, the construction integration model explains that deep understanding is achieved when semantic links between concepts are formed in memory.

This proposition, of course, is consistent with the findings of this investigation. If learners in the unstructured condition sought to integrate the information between documents, they had to make inferences about the relations. Because of their lack of prior knowledge, success in this endeavor was tenuous, at best. Those in the hierarchical condition were given only implicit information about these relations by virtue of link placement. Those in the clustered condition, however, were explicitly told about the relations between animals. According to the construction integration model, when participants in the clustered group attended to the semantic information provided by the links, they should have come away with a more well-integrated understanding of the material because the defined links better supported the integration process. The navigation data indicate that the participants in the clustered group generally performed on a par with those in the other groups; their attention to this more explicit information was indeed associated with enhanced problem-solving ability.

An alternative explanation is that the present results are simply due to a reduced cognitive load on learners (Sweller, 1993; Sweller & Chandler, 1991, 1994). Sweller explained that, for some tasks, the amount of information required to be processed at once can adversely affect learning. The idea is that when a learning task requires the simultaneous processing of several interacting elements, the cognitive load may be too great for limited working memory capacity. When link relations are more explicitly defined, the result may be a freeing of space in working memory that allows learners to focus their attention and working memory resources on information they are reading and attempting to integrate. Indeed, Sweller (1993) stated that "when presenting new material, information structures that require learners to unnecessarily split their attention between multiple sources of information ... can impose an excessive cognitive load that interferes with learning" (p. 1). By supplying explicit information about the relations between two documents, learners may be freed from the burden of keeping information from both sources in working memory while trying to find the connection between them. Instead, they are free to take in the information as it is read and apply it to the unifying theme with which they have been provided.

Regardless of which explanation is more accurate, the present results are important to hypertext system design and classroom learning. Soloway, Guzdial, and Hay (1994) based an approach to generalized system design on the premise that learners have different needs than other types of users. They argued that because all learners are users but not all users are learners a shift is necessary from user-centered design to learner-centered design (LCD) if educational software is to be effective. To guide the development of learner-centered software, Soloway et al. proposed the TILT model (tools, interfaces, learner's needs, tasks) of system design, which is based on the constructivist approach to learning. The major focus of TILT is to support learners' needs through appropriate tasks, tools, and interfaces.

This study has identified one important need of novice learners. Specifically, novices require information about the semantic relations between ideas and this study's participants relied heavily on the system tools and interfaces to help them find meaning in the link structure. The hierarchical group attended to the structure they were given, whereas the unstructured group worked to identify the latent hierarchical structure as they worked. The navigation data indicate that the clustered group navigated the system as though it were a hierarchy, but the mapping posttest indicates that they clearly attended to the semantic link labels as well. This group, then, took advantage of a number of features to find meaning in the link structure.

In short, participants' behavior indicates that they were in need of and sought out help to find meaning. In other words, they took advantage of available scaffolding to aid them in making sense of the information embedded in a hypertext system's link structure. Scaffolding is a method of pushing learners to expand their intellectual boundaries while supporting their efforts within the context of their current skill level. In this way, they can grow into expertise without feeling lost or overwhelmed. Scaffolding is generally removed when the learner's skill level increases. Whether provided with implicit information in a hierarchy or explicit information within link labels, the learners in this study benefitted from the presence of cues to meaning. This point is particularly important for hypertext design in ill-structured domains (like literature and history), which may not easily be structured in a strict hierarchy. I argue, then, that defining links for novice users may be as profitable a way to scaffold the use of hypertext for meaningful learning as a hierarchy.

How can an educator ensure that beginning students are using the links that are most relevant to their learning goals? After all, the learning benefit was only associated with the clustered group's use of defined links. This issue is problematic for hypertext design because one of the great benefits offered by the technology is the freedom it offers learners to follow the paths of their choice. These results indicate that this freedom may come at some cost to the novice learner. The use of programmed guided tours through hypertext systems has been explored as a way to ensure exposure to specific sectors of a system and to keep users oriented in hyperspace (Hammond & Allinson, 1988, 1989). This approach has had some success, but it also creates a largely instructivist environment by taking a great deal of control away from the learner.

Nevertheless, this study has shown that novices studying biology are indeed aided in their endeavors when their understanding is scaffolded by semantically defined system links. Other experimental evidence also supports this conclusion. In a study of text-based learning, McNamara, , Songer, and Kintsch (1996) were able to show that novice learners benefitted from the addition of bridging phrases that defined the relations between ideas. They showed improvement on problem-solving posttests. High-knowledge learners in that same study, however, benefitted more from texts that did not include this form of scaffolding. On the basis of that study, then, it is predicted that hypertext links that can adapt to learners' skill levels by varying the amount of semantic information they offer will improve the learning outcome for students of all knowledge levels. Indeed, Soloway et al. (1994) proposed that scaffolding tools must be adaptive to the learner's level of expertise. The use of adaptive hypertext, a method of tailoring available links to individuals' goals, is being explored in this context (Kay & Kummerfeld, 1994; Kobsa, Nill, & Fink, in press).

In conclusion, this study was able to show that novice learners benefitted from a highly coherent hypertext system. This benefit was dependent, however, on their navigation paths. That is, learners profited when they attended to the tools that provided coherence. On this basis, it is suggested that a major benefit of hierarchies is their ability to offer information about the relations between topics. In the context of LCD, it is suggested that systems designed for use by novices supply learners with information about link relations, either through structure or more explicit means. It is also predicted, however, that as learners gain knowledge of a domain, they will benefit from the removal of explicit scaffolding. That is, more expert learners will gain more benefit by applying their prior knowledge to create coherence than by the presentation of tools like semantically defined links.

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