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ABSTRACT

A possible method of solving problems of knowledge representation and system adaptation in a hypermedia environment was examined. The method, based on the notion of semantic networks, uses the technique of knowledge mapping. In the process of reading a hypermedia document, the learner constructs a knowledge map (KM) specifying the relationships between concepts in the domain. The resulting map can be used to recognize learner misconceptions and identify potential instructional opportunities. The prototype KM system was tested with 36 undergraduates assigned to 1 of 3 groups using different versions of the system (browse, map, and relate), which allowed the learner to use a KM, construct a KM without feedback, or construct a KM with feedback. Subjects also completed paper and pencil pretests and posttests to identify the relationships between concepts introduced. All participants gained a significant amount of knowledge about the content. The browse group performed better on the short answer test, perhaps because participants in the other conditions were so involved in processing their KMs they did not study the concepts as well. A hypermedia system of this sort may provide an effective means of judging when a learner has attained some level of understanding of the domain. The system could then provide a new and appropriate level of detail for the learner. Four tables and five figures present study data. A 25-item list of references and 4 appendixes illustrating KMs and analysis procedures are included. (SLD)

Adaptive hypermedia instructional systems: Possibilities for learner modeling

by

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Running Head: Learner modeling for hypermedia

Adaptive hypermedia instructional systems: Possibilities for learner modeling

Much has been made of the parallels between the representational architecture of hypermedia and current conceptions of human memory. Cognitive theories of learning emphasize the interconnections of information in a structural associative network composed of both the stored information and the relational links connecting the information (Anderson & Bower, 1973; Norman, Gentner, & Stevens, 1976). The associative nature of these relationships is also central to hypermedia systems, but few systems allow authors to specify semantic relationships when defining links between nodes (Collier, 1987). To facilitate the movement of hypermedia systems from sophisticated information presentation systems toward effective knowledge representation systems for instruction, more attention should be placed on the underlying processes required for human knowledge acquisition and representation in memory. Specific inquiry into the fundamental aspects of nodes (text fragments) and links ("branches" to other nodes) is necessary in order for hypermedia systems to more readily parallel the organization of human memory. In particular, it is important to examine various ways that hypermedia systems can convey to learners the underlying organization of the information in a domain.

One of the major problems facing designers of hypermedia systems for education is to produce a system that does not simply present information, but fosters learning through effective pedagogical strategies (Nelson & Palumbo, in press). Hypermedia provides ways to structure small, discrete units of information (nodes) into large documents which are viewed/read by following the paths (links) between nodes provided by the author of the document. The power of hypermedia applications lies in the ability to present information in a nonlinear sequence, mirroring some of the associational power of human memory (Collier, 1987). As a presentation medium, hypermedia offers the potential to provide large databases of information that can be traversed by learners for a variety of purposes. But the motivational impact of learner-directed exploration of a hypermedia database is overshadowed by problems of disorientation and other difficulties (Duffy & Knuth, 1991; Nelson & Joyner, 1990). Further, using hypermedia as a presentation system does not guarantee that the information will be accurately and adequately transferred to the knowledge base of the learner (Nelson, in press). Establishing the most useful pathways through a hypermedia document with "tours" (Hammond, 1989) or "guides" (Oren, Salomen, Kreitmen, & Don, 1990) can increase the likelihood that learners will view the critical information, but there is little evidence that providing quick access to a large body of information will promote learning any more than a library does.

Few current hypermedia systems wrestle with the challenges of adaptive instruction as is common in other forms of intelligent computer-assisted instruction. An adaptive hypermedia system that anticipates the needs of the learners, and dynamically adjusts the organization and presentation of information accordingly (Oren, 1987), may be a more effective utilization of the technology for instruction. Aspects of artificial intelligence can be incorporated in hypermedia systems to provide guidance to the learner in a flexible and efficient manner (Barker, 1990). Adaptive access to large hypermedia databases could be achieved by considering the learner's prior history of interaction, current knowledge, and preferences. Decisions could then be made by the system with respect to which nodes and links to provide, how to organize the nodes, and which instructional activities to provide.

The research reported in this paper examines a possible method to solve problems of knowledge representation and system adaptation in a hypermedia environment. The method, based on the notion of semantic networks (Anderson & Bower, 1973; Collins & Quillian, 1969), uses the technique of knowledge mapping. In the process of reading a hypermedia document, the learner constructs a knowledge map specifying the relationships between concepts in the domain.

The resulting map can be used to recognize learner misconceptions, and identify potential instructional opportunities.

The method: Eliciting knowledge structures

Theories of associative memory and semantic networks (Anderson & Bower, 1973; Collins & Quillian, 1969) assume that memory is organized as a network of concepts that are connected through various relationships. It is possible to elicit an individual's conceptual organization using several techniques including relatedness ratings (McKeithen, Reitman, Reuter, & Hirtle, 1981; Schvaneveldt, Durson, Goldsmith, Breen & Cook, 1985), and pattern notes or knowledge maps (Jonassen, 1987). Such techniques can be used not only to elicit conceptual organization, but to convey information through spatial representations in order to facilitate the acquisition of declarative and procedural information, especially technical material (Rewey, Dansereau, Skaggs, Hall, & Pitre, 1989). Students can also be taught to construct knowledge maps in order to solidify understanding of the relationships between concepts in a domain (Novak, 1990). It is apparent from this research that knowledge maps may provide the means for students to develop effective, personalized transitions between the information in a hypermedia document and the cognitive structures of the learner.

The system described in this paper employs knowledge mapping as a central learning activity, along with aspects of intelligent tutoring systems (Wenger, 1987) that are used to analyze and identify student misconceptions. Intelligent tutoring systems typically utilize an "expert model" that represents the knowledge of a domain expert in some format that can be stored in a computer (Anderson, 1988) and a "learner model" that represents in a similar way the knowledge of the learner (VanLehn, 1988). An intelligent tutoring system can diagnose learner problems by examining the current state of the learner's knowledge in comparison to the expert model (Orey & Nelson, in press), and then provide appropriate instructional interactions to help alleviate the problems. The system discussed below assembles an "expert" model as an expert defines concepts and relationships in the domain, representing the relationships between concepts as a directed graph (Alty, 1984; Carre, 1979). The learner then uses the system to construct a knowledge map, and the system compares the learner's map (represented in the same format as the expert) to the expert model in order to identify and diagnose misconceptions.

A prototype hypermedia system fitted with "tools" that allow learners to construct knowledge maps of a domain, using the resulting maps for diagnosis of learner misconceptions, was developed for this research. The system consists of two components: a Knowledge Editor and a Knowledge Map tool. The Knowledge Editor allows an "expert" (a teacher) to identify the concepts in the domain and to specify relationships between concepts. Information is entered by filling in forms (See Figure 1), and the concept, along with its definition and relationship(s) to other concepts, is added to the database. The Knowledge Map tool aids the learner in constructing a map of the concepts and relationships in the domain. Initially, the map is blank, and the learner constructs the map by "placing" concepts in the two-dimensional space, and "connecting" concepts with lines to indicate the relationships (See Figure 2). At any time, the learner may view the definition of a concept by clicking on the concept name in the list, causing the concept description to be displayed in a window on the screen. In this way, the learner constructs a representation of knowledge in the domain which can be subsequently presented to others (or self) for discourse or study.

Figure 1.
The Knowledge Editor.

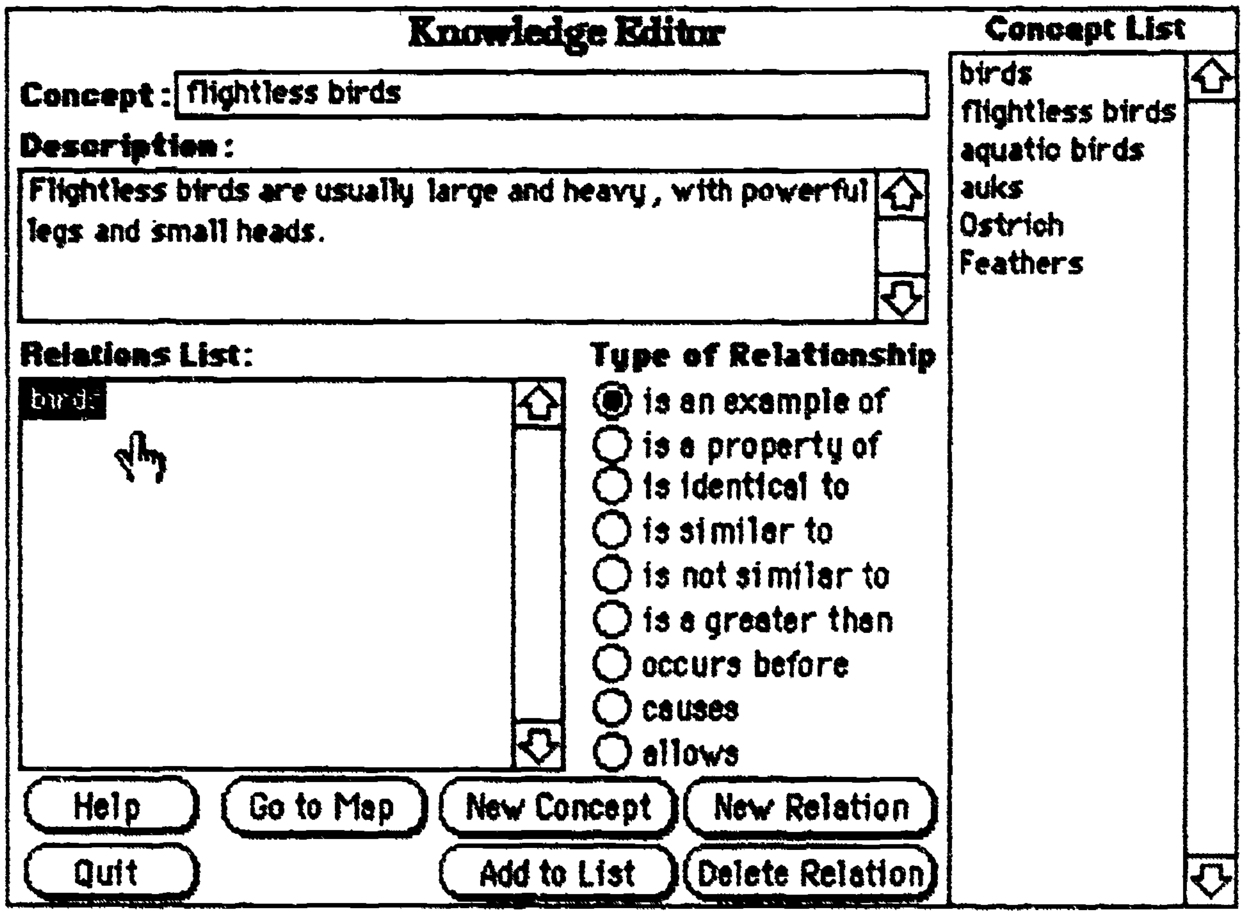
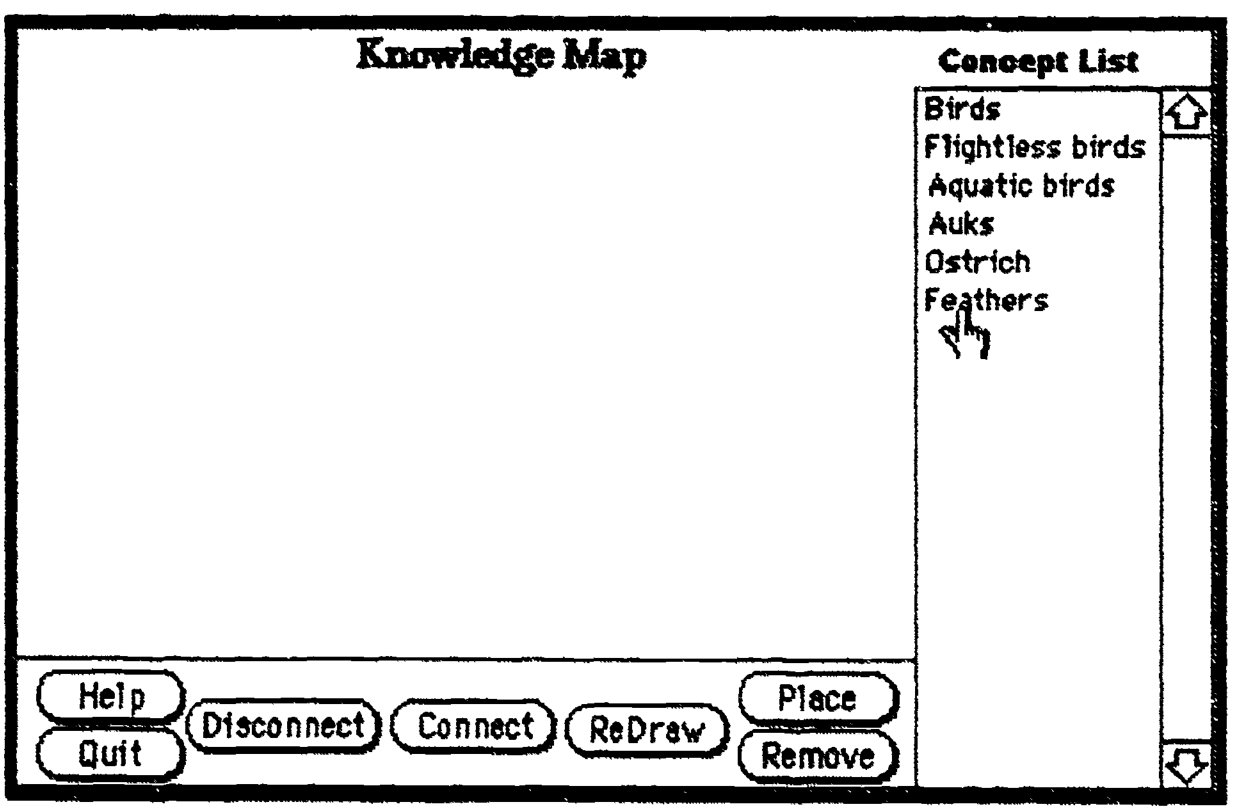


Figure 2.
The Knowledge Map tool.



There are several ways that an adaptive hypermedia system such as the one described above could be used for instructional purposes. As one possibility, the system could monitor the learner's activities as the map is being constructed For example, if a learner indicates that an apple is a vegetable, the system would intervene at the point of the mistake and display further information designed to modify the misconception. Alternatively, the mapping activity could be used as a "pretest" in order to determine the current state of the learner's domain knowledge. In this case the learner would construct the map without intervention by the system. Diagnosis of misconceptions would occur after the learner had finished the map. Both alternatives were examined in the research reported below.

Testing the prototype system

Testing and evaluation of the Knowledge Map system focused on whether allowing learners to view and construct knowledge maps for a domain would facilitate acquisition and retention of the information, and whether the knowledge representation strategies employed in the system could be used to effectively diagnose and remediate learner misconceptions. In order to evaluate the system's performance, a comparative study was undertaken using three different versions of the software.

Participants and Design

Thirty six participants randomly selected from a pool of undergraduates taking Educational Psychology classes used the Knowledge Map system during Fall, 1991 courses. The participants were randomly assigned to one of three groups that utilized different versions of the Knowledge Map system (Browse, Map, and Relate). A pretest-posttest design was employed in order to assess the knowledge gains of the participants when using the different versions of the system.

Materials

Three versions of the Knowledge Map system, each containing identical content, were developed for the experiment. The systems were developed using Hypercard on the Macintosh computer. The content was adapted from a text on hypertext (Shneiderman & Kearsley, 1989), and was entered using the Knowledge Editor. One version (Browse) was developed to present the information using a knowledge map constructed by an expert (See Appendix A). A second version (Map) was developed so that participants could use the Knowledge Map tool to construct a map of the domain (See Appendix B), but no feedback was provided to the participants using this version. The third version (Relate) was identical to the second, except that an expert model was included, and the software was programmed to provide instructional feedback in order to help learners construct maps that were identical to the expert. Specifically, the Relate version informed the learners when an attempt to connect unrelated concepts was made, and refused to make connections that were not identified in the expert model. In addition, this version of the software also required participants to specify the type of relationship between concepts when making a connection (See Appendix C). All versions of the software contained instrumentation that recorded the participant's interactions with the software, as well as the diagnoses made by the system.

In addition to the different software versions, paper-and-pencil tests were constructed for use in the pretest-posttest experimental design. These tests contained 13 multiple choice tests items that required the participants to identify the type of relationship between pairs of concepts. The tests also contained 13 short-answer items that required the participants to write a short definition of each concept in the domain.

Procedure

Participants were pretested on their knowledge of the content one week prior to using the Knowledge Map system. To test the software, participants worked with the Knowledge Map system for two hours during one of the regularly scheduled class periods. They were trained to use the system through demonstration and practice with a system that operated exactly like the prototype system, but contained different content. Printed reference materials describing the operation of the software were used for the training, and were available to the participants during the experiment. When the participants were comfortable using the practice system, they proceeded with the experimental task. All participants were informed that they should complete the experimental task in preparation for a test on the content contained in the program. Participants in the Browse group accessed the information in the map by clicking on the various map components and reading the information presented. Participants in the other two groups (Map and Relate) used the Knowledge Map system to construct graphical representations of the concepts and relationships in the domain. All participants completed the paper-and-pencil posttest immediately after finishing the experimental task. A delayed measure that required participants to produce a map of the concepts in the domain was administered three weeks after the experimental session.

Results and Discussion

The data collected in the study included the matrices maintained by the software that represented the Knowledge Maps constructed by each participant (Map and Relate groups only), the maps constructed by the participants (as a result of the experimental task and three weeks delayed), the pretests and posttests that assessed knowledge gained by using the software, and qualitative data collected by the software describing each participant's patterns of interaction. Analysis focused on the diagnostic capabilities of the software used by the Relate group, the conceptual organization exhibited by participants who used the different software versions, qualitative descriptions of the strategies participants developed when using the software, and comparisons of learning as evidenced by performance on the tests.

Diagnostic Capabilities

The diagnostic capabilities of the Knowledge Map system were evaluated in several ways, primarily through comparisons between the results of the Map group and the Relate group, since the Browse group did not construct knowledge maps. The software maintained a data structure in the form of a matrix that represented the maps constructed by the participants. These matrices were analyzed to determine the total number of links made between concepts, the number of correct links, and the number of incorrect links (See Table 1). A link was classified as incorrect if comparison to the expert model showed that a link was identified that should not have been made, or if a link was not identified when it should have been. An ANOVA performed on the data revealed no significant differences between groups for total links identified ($F[1,22] = 1.742$, $p < 0.2005$), but there were significant differences for correct links ($F[1,22] = 102.414$, $p < 0.0001$) and for incorrect links ($F[1,22] = 102.414$, $p < 0.0001$). Scheffé's test confirmed that the Relate group made significantly more correct links, and significantly fewer incorrect links.

This result is not surprising, since the software for the Relate group did not allow participants to identify an incorrect link. When a user attempted to connect two concepts that were not specified as related in the expert model, the software informed the user that the two concepts were not directly related. This feature of the diagnostic/instructional process inherent in the software used by the Relate group also produced another interesting result: the correct number of links and the total number of links for participants in the Relate group were the same. However, some links in the Relate group that were classified as incorrect in the analysis were actually missing because the participant ended the session without connecting all concepts in the map. In the analysis procedure, if no link was made when it should have been, the score for incorrect links was increased. In this sense, "incorrect" means "not identified at all", not "incorrectly identified". Future versions of the software will have to assure that learners do not quit until all concepts are correctly connected in the map.

Table 1.

Mean number of linked concepts in Map and Relate conditions.

Group	Total Links		Correct		Incorrect	
	Mean	S. D.	Mean	S. D.	Mean	S. D.
Map (N = 12)	13.25	3.646	4.25	2.094	9.75	2.094
Relate (N = 12)	11.75	1.485	11.75	1.485	2.25	1.485

The software used by the Relate group also required participants to identify the type of relationship between two concepts when connecting the concepts on the map. Results from the interaction data files were examined to determine the total number of attempts made to identify the relationship between concepts, and the number of correct and incorrect identifications of relation types. The means for these categories are presented in Table 2, along with the the percentage of attempts that were incorrect. The 46% figure for incorrect identification of the type of relationships between concepts is quite high, and represents an interesting and unanticipated strategy that participants utilized. Observation of the participants during the experiment revealed that when prompted by the software to identify the type of relationship between two concepts, the participants frequently just "guessed". The software then informed the user of the error, and the user was given another chance to identify the type of relationship. Participants typically just clicked on different relation types until the system let them continue because they had finally selected the correct relation. Subsequent versions of the software will have to be modified in order to discourage this strategy, but it was interesting to see the strategy develop spontaneously as the participants used the system.

Table 2.

Numbers of correct and incorrect relations identified by participants in the Relate group.

	Total Attempts	Incorrect	Correct	% Incorrect
Mean (N=12)	25.76	13.29	12.47	46.0
S. D.	8.34	9.92	3.02	24.0

Conceptual Organization

One of the major purposes of the Knowledge Map software is to help learners construct maps that reflect the organization of concepts in a domain as specified by an expert. If the system is successful, there should be significant differences between the resulting conceptual organization of the Relate group (where the software forced the learners to construct maps that were identical to the expert representation) and the Map and Browse groups (where the software did not force adherence to the expert model). As mentioned earlier, techniques for eliciting and analyzing conceptual organization have been developed that can provide indications of the effectiveness of the software for meeting its goals. Since participants in the Map and Relate groups produced maps both as a part of the experimental task (immediate), and as a delayed measure three weeks following the experiment (delayed), data was available for comparisons between versions of the software. In addition, since all three groups completed concept maps three weeks after the experiment, data existed to compare the conceptual organization of all participants after some delay.

An initial assumption made for purposes of analysis was that the maps constructed by the participants could be treated as directed graphs (Jonassen, 1987). The distance between two concepts on the maps was defined as the number of lines between pairs of concepts in the map. A distance matrix was formed for each participant by counting the intervening lines between each of the 13 concepts (See Appendix D for an example). The distance matrix for each participant was then compared with a matrix formed by analyzing the expert representation in the same way. Each cell in the participants' matrices was then subtracted from the corresponding cell in the expert matrix, and the results were used to construct a difference matrix for each participant. The difference matrices for each participant in the Relate and Map groups were then compared using a t-test procedure between each cell in the difference matrices. Cells where significant differences were found by the t-test procedures are given in Figure 3 for the immediate measures.

Figure 3.

Significant differences ($p < 0.05$) between Map and Relate groups for knowledge maps immediately after experimental task.

	Computer instruction	authoring	navigation problems	nonlinear access	searching	browsing	links	nodes	hypertext	structure	tours	networks	hierarchies
Computer instruction													
authoring													
navigation problems	*	*											
nonlinear access													
searching		*		*									
browsing													
links			*										
nodes			*										
hypertext													
structure													
tours								*	*				
networks													
hierarchies													

All of the significant differences identified by the t-test procedures as shown in Figure 3 were in favor of the Relate group. That is, in all cases the differences between the Relate group and the expert model were significantly less than the differences between the Map group and the expert model. These results indicate that the conceptual organization of the participants in the Relate group was more similar to the expert model than the participants in the Map group immediately following the experimental task. Again, this is not surprising since the software used by the Relate group did not allow users to connect concepts that were not connected in the expert model.

Similar analyses were completed on the maps constructed by participants after a three week delay. Figure 4 shows the results of the t-test procedures between the Browse and Map groups, the Browse and Relate groups, and the Map and Relate group. Some of the differences in conceptual organization were maintained even during a three week delay. It is interesting to note, however, that the differences between the Map and Relate groups do not remain between the same concept pairs as in the immediate measures. Instead, new differences between other concept pairs emerged in the delayed measure.

Figure 4.

Significant differences between groups for knowledge maps after three week delay.

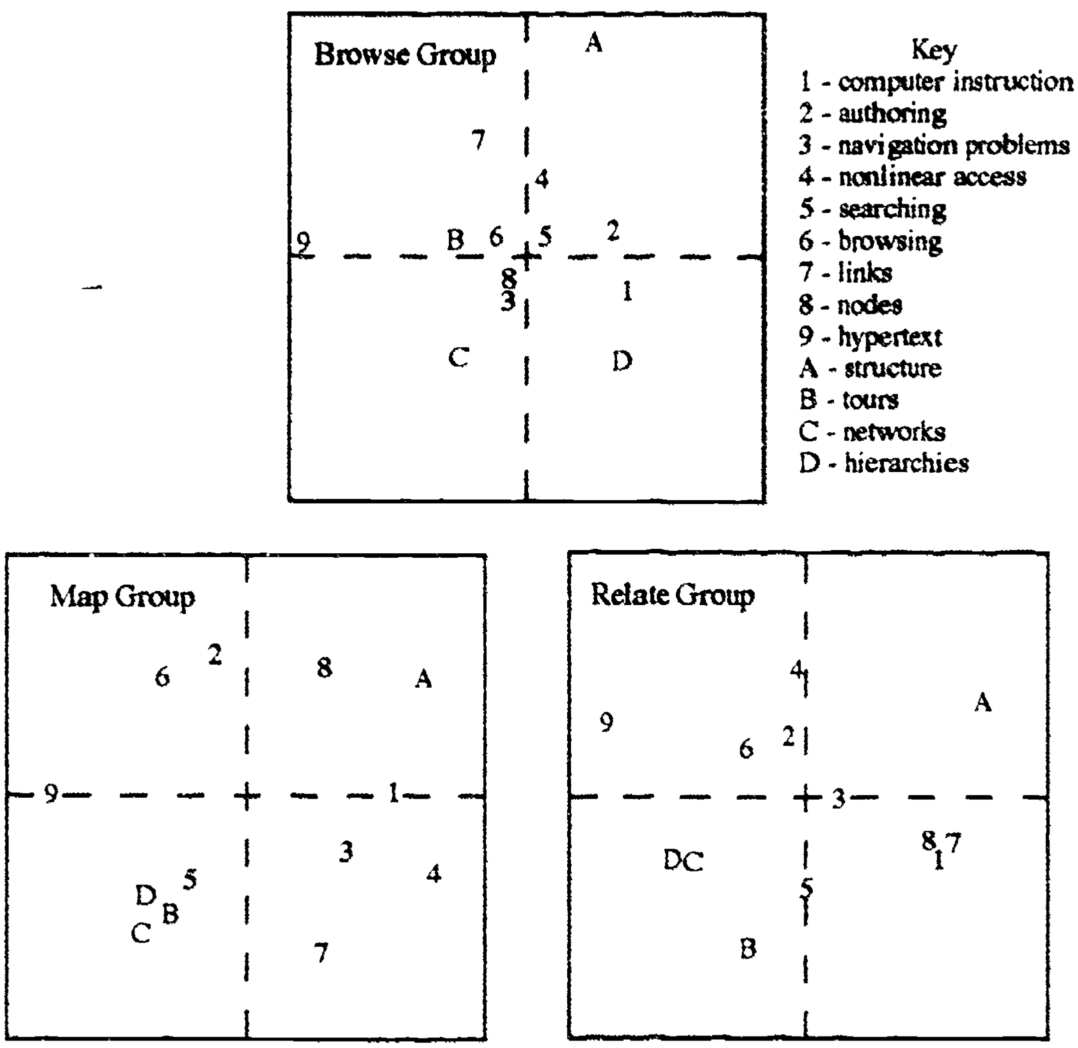
	Computer instruction	authoring	navigation problems	nonlinear access	searching	browsing	links	nodes	hypertext	structure	tours	networks	hierarchies
Computer instruction													
authoring													
navigation problems	x												
nonlinear access													
searching	x			*									
browsing				*									
links		#											
nodes													
hypertext													
structure			*	* #	x			* #	* x				
tours				#		*				* x			
networks										* #			
hierarchies							x				*		

* Browse vs. Map
x Browse vs. Relate
Map vs. Relate

A second phase of analysis utilized nonmetric multi-dimensional scaling (MDS) procedures to map the semantic distances between concepts. For the delayed measure, all of the pairwise values in the matrices for each participant were averaged to produce a mean distance matrix for each pair of concepts in the three groups (See Appendix D for an example). It can be assumed that the higher the mean for a given pairwise value, the greater the spatial distance between those concepts in the maps, and therefore the less the two concepts are related (Jonassen, 1987). The mean distance matrices were scaled using the statistical procedure ALSCAL (SPSS-X User's Guide, 1988). Goodness-of-fit measures were computed using Kruskal's Stress Formula 1 for each group's average distance matrix, with an RSQ value indicating the proportion of variance accounted for by the MDS model. For the Browse model, stress = 0.258, RSQ = 0.682, for the Map model, stress = 0.302, RSQ = 0.458, and for the Relate model, stress = 0.29, RSQ = 0.511. Since stress values of 0.10 are considered good (Jonassen, 1987), the stress and variance of the models in this experiment are relatively high. However, the stress values are not the critical issue for purposes of this study. Rather, the plotting of the stimulus weights as computed by the MDS procedure (Figure 5) provides the information of interest, that is, the spatial maps of the average distances between concepts for each group.

Figure 5.

MDS solutions for average concept organization of each group.



Some interesting consistencies between groups are evident in the MDS solutions plotted in Figure 5. First, the "hypertext" concept does not cluster with any other concepts, perhaps indicating a superordinate relationship, with other concepts clustered around it. The same is true of the "structure" concept and its relationships to "networks" and "hierarchies". Other concepts tend to cluster in all MDS solutions, such as "networks" with "hierarchies", and "browsing" with "authoring". It is also interesting to note that the concepts in the MDS solution for the Browse group tend to cluster around the center, while the Map and Relate group appear to have more "spread" between concepts.

Qualitative Results

The software used by participants in the Map and Relate groups recorded every action taken by each participant while using the software. The data from these files, coupled with observations made by the experimenters, give an indication of the differences in the ways that participants approached the experimental task. The mean frequencies of each type of action are summarized in Table 3, including results of ANOVA procedures comparing the means between Map and Relate groups. As can be seen, there were no significant differences between groups except for the "Remove" action. Participants in the Map group removed more concepts from the map than did participants in the Relate group. Although the reasons for this difference are not clear, the fact that some concepts were removed from the map may have contributed to the differences in conceptual organization that were noted earlier. Observations by experimenters indicate that it is also possible that the concepts were removed for "cosmetic" reasons, that is, participants were trying to "clean up" the appearance of their maps, and eventually placed the concepts back on the maps.

Table 3.

Means and ANOVA results of various actions taken by participants while using the software.

	Map Group		Relate Group			
	Mean	S. D.	Mean	S. D.	F value	*p*
View	36.75	27.13	31.08	7.9	.483	.494
Place	12.25	7.45	17	5.33	3.23	.086
Move	95.08	55.41	105.4	39.5	.277	.604
Connect	23.67	16.26	35.42	19.66	2.54	.125
Disconnect	4.17	9.97	.08	.29	2.011	.1702
Remove	2	1.86	.67	1.07	4.632	.043
Redraw	2.5	2.54	6.25	6.97	3.67	.094

The qualitative data collected by the software also indicated differences in strategies used by participants to complete the mapping activity. Some participants tended to first place all of the concepts in the map, then link the concepts and rearrange the map in order to make the map easier to read. Other participants tended to place and link concepts in pairs, keeping the map in acceptable spatial organization as they placed each pair of concepts. Finally, some participants placed and linked the concepts using one or the other of the strategies mentioned, then viewed all of the concepts repeatedly. Apparently, they were studying the map in preparation for the posttest. These different strategies appeared to develop spontaneously, since the experimenters did not advocate a certain strategy for the task. It should be noted that these strategies were used by participants in both groups, indicating that the differences in the software did not influence the strategies used by participants to complete the task.

Post-experiment comments made by some participants also indicated improvements that could be made to the Knowledge Map software. First, several participants wanted to the map to specify the type of relationship between concepts, rather than just a line indicating that the concepts are related. Some participants in the Relate group also expressed frustration that the "expert model" did not allow them to construct relationships that they felt existed. Apparently they wanted to construct a richer network in terms of relationships between concepts, but the expert model was not designed to allow such richness.

Measures of Learning

Traditional measures of learning utilizing paper and pencil tests were also used to evaluate the effectiveness of the Knowledge Map system. As mentioned earlier, multiple choice and short answer test items were administered to all participants as a pretest, and as a posttest immediately following the experimental task. Gain scores were computed for all participants by subtracting the pretest scores from the posttest scores. The mean gain scores for each group are given in Table 4. ANOVA procedures revealed no significant differences between groups on the multiple choice items ($F[2,33] = 0.811$, $p < 0.453$), but there were significant differences on the short-answer items ($F[2,33] = 3.341$, $p < 0.0477$). A Scheffé test indicated that the gain scores for the Browse group were significantly greater than the Map group, but not the Relate group.

Table 4.

Mean gain scores on paper-and-pencil tests.

Group	Multiple Choice		Short Answer	
	Mean	S. D.	Mean	S. D.
Browse (N = 12)	3.0	2.256	7.583	3.397
Map (N = 12)	1.197	2.999	3.917	3.872
Relate (N = 12)	1.583	3.204	5.417	0.917

All participants, regardless of experimental group, gained a significant amount of knowledge about the content. Paired t-tests showed significant differences between the pre and post multiple choice items for the Browse group ($t = 4.606$, $df = 11$, $p < .0008$), the Map group ($t = 2.214$, $df = 11$, $p < .0489$), but the Relate Group did not show significant improvement on the posttest for multiple choice test items ($t = 1.715$, $df = 11$, $p < .1149$). Similar improvements between the pre and post short-answer items were revealed for the Browse group ($t = 7.734$, $df = 11$, $p < .0001$), the Map group ($t = 3.504$, $df = 11$, $p < .0049$), and the Relate Group ($t = 5.909$, $df = 11$, $p < .0001$). The fact that the Browse group performed better on the short-answer test was not expected, but can be easily explained. The cognitive load associated with the Knowledge Map software for the Map and Relate versions must have interfered with the processing of the content. Participants were so involved with constructing their maps that they did not take the time to read and study the descriptions of the concepts. They were only interested in determining the relationships between concepts that were indicated in the concept descriptions so that they could connect the appropriate concepts in the map.

Conclusions: Future directions

Further testing of the approach to learner modeling implemented in the Knowledge Map software is needed, but if this or other methods of knowledge representation and diagnosis prove valid and useful, future hypermedia systems could use the knowledge maps constructed by a learner to organize and "filter" information in a hypermedia document. Using the Knowledge Map tool in a "pretest" mode, a learner could specify the organization of a large document, and the system could then structure the information to adapt to the learner's understanding of the domain. At the same time, the system could identify misconceptions and recommend further study of the areas where problems were identified. Such an approach may reduce the disorientation often experienced by learners when browsing a hypermedia document, and may better facilitate learner exploration and ultimate transfer of the information in the hypermedia system to the learner's memory.

Further research also needs to focus on when is the best time for intervention by the system. The method implemented with the Relate group provided immediate feedback when an error was made. As noted above, participants who used the Relate version of the software expressed frustration that the system was so inflexible, and many participants adopted a "guessing" strategy to identify the type of relationship between concepts, rather than reading the concept descriptions and inferring the type of relationship through reasoning processes. On the other hand, using this version of the software resulted in conceptual organization that was generally more similar to the "expert" than the other versions.

The richness of the expert model also posed problems in this study. Participants in the Relate group mentioned that they felt there were relationships between concepts that the system would not let them identify; that there were more relationships that should have been allowed. This problem could be alleviated by adopting a representation that uses weightings instead of an "all or nothing" representation of expert. The expert model implemented in this study merely indicated that a pair of concepts was related, not the degree to which all concepts were related to all other concepts. Future versions of the software will need to address this problem.

Finally, a hypermedia system that contains an expert model and a method for learner modeling such as the mapping activity used in the Knowledge Map software may provide an effective means of judging when a learner has attained some level of understanding of the domain. The system could then provide a new level of detail that is appropriate to the learner's current knowledge. In order to implement such a hypermedia system, it would be necessary to organize the hypermedia database in "layers" of increasing specificity so that learners could be presented more detailed descriptions and relationships after they had mastered the initial content. This would require that maps be three-dimensional, increasing the complexity of the learner's task as well as the methods used for diagnosis and knowledge representation. Further research is needed to determine if the benefits of such a system are worth the effort.

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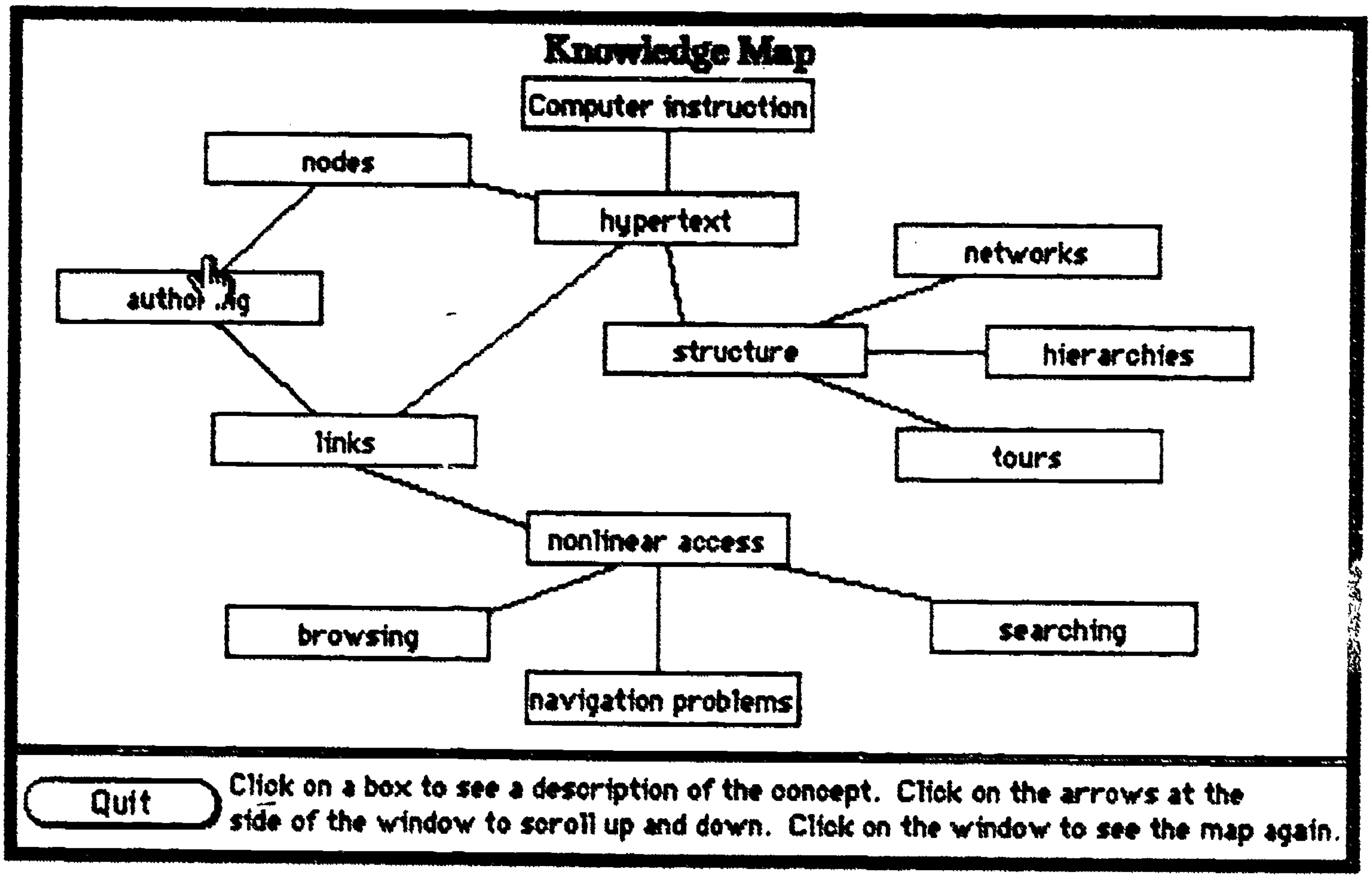
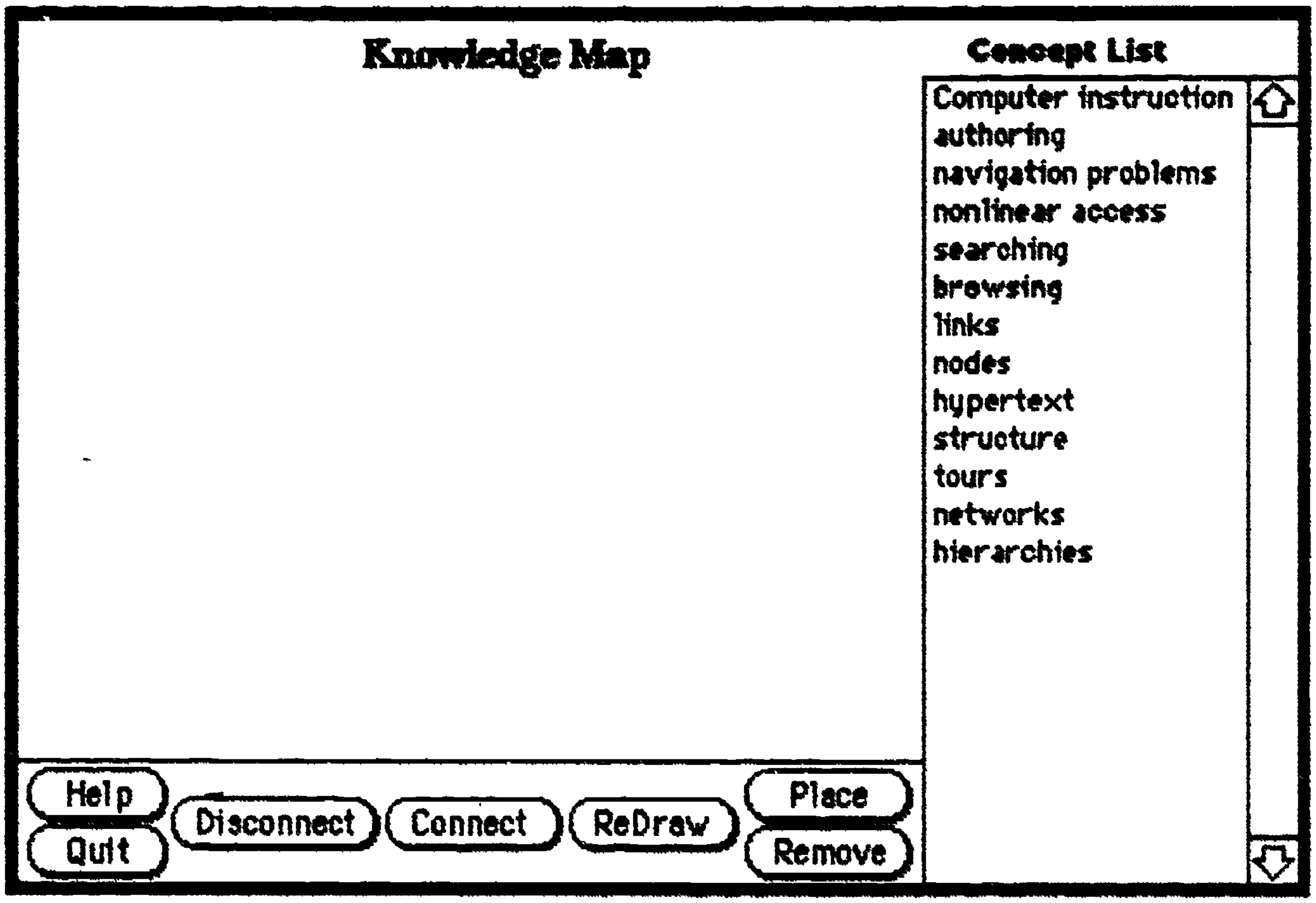
Appendix A

"Expert" map used by the Browse group



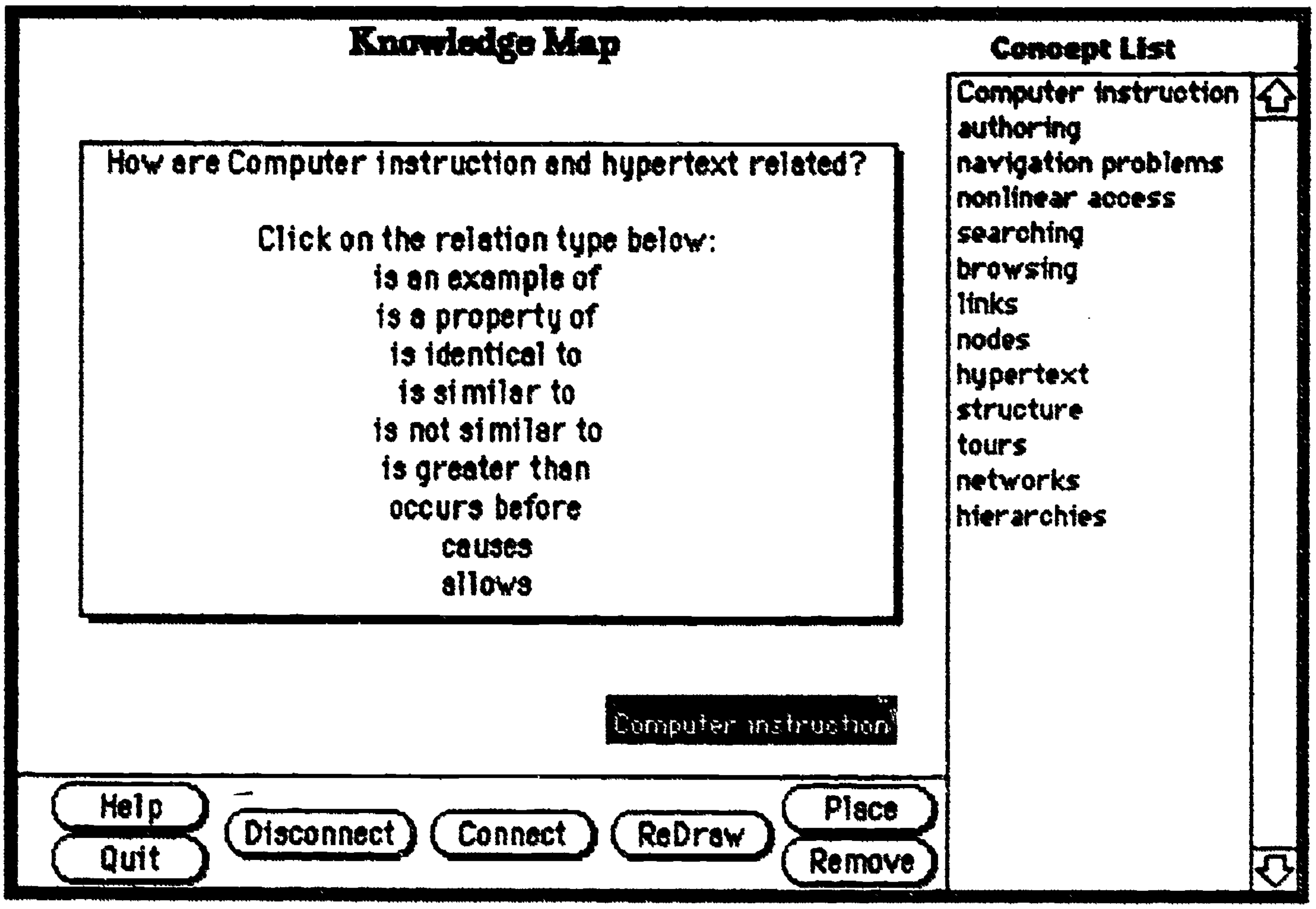
Appendix B

Knowledge Map system used by the Map group



Appendix C

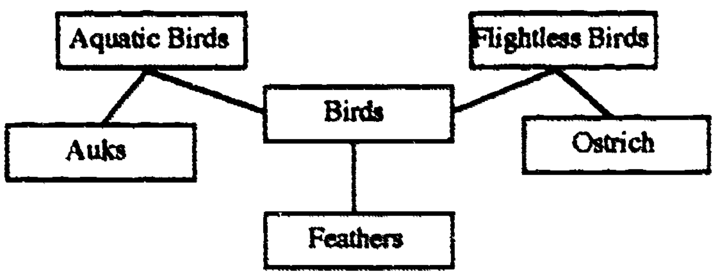
Knowledge Map system used by the Relate group



Appendix D

Analysis procedures

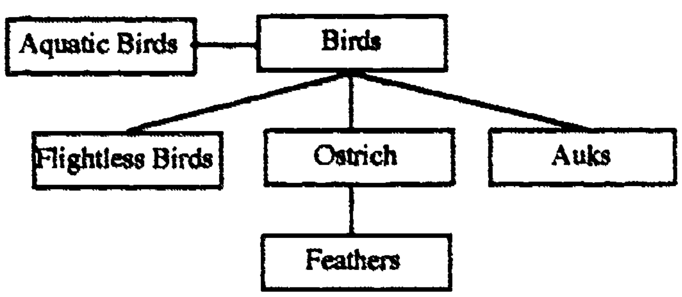
The Expert's Knowledge Map



The distance matrix derived from the map

	Birds	Feathers	Aquatic Birds	Auks	Flightless Birds	Ostrich
Birds	0					
Feathers	1	0				
Aquatic Birds	1	2	0			
Auks	2	3	1	0		
Flightless Birds	1	2	2	3	0	
Ostrich	2	3	3	4	1	0

The Student's Knowledge Map



The distance matrix derived from the map

	Birds	Feathers	Aquatic Birds	Auks	Flightless Birds	Ostrich
Birds	0					
Feathers	2	0				
Aquatic Birds	1	2	0			
Auks	1	3	2	0		
Flightless Birds	1	3	2	2	0	
Ostrich	1	1	2	2	2	0

For each cell in the matrix
The Student Model . . .   minus the Expert Model . . .   equals the difference matrix

	Birds	Feathers	Aquatic Birds	Auks	Flightless Birds	Ostrich
Birds	0					
Feathers	1	0				
Aquatic Birds	0	0	0			
Auks	0	0	1	0		
Flightless Birds	1	0	0	0	0	
Ostrich	1	0	0	0	1	0

	Birds	Feathers	Aquatic Birds	Auks	Flightless Birds	Ostrich
Birds	0					
Feathers	2	0				
Aquatic Birds	1	2	0			
Auks	1	3	2	0		
Flightless Birds	1	3	2	2	0	
Ostrich	1	1	2	2	2	0

	Birds	Feathers	Aquatic Birds	Auks	Flightless Birds	Ostrich
Birds	0					
Feathers	-1	0				
Aquatic Birds	-1	-2	0			
Auks	-1	-3	1	0		
Flightless Birds	0	-3	-2	-2	0	
Ostrich	0	-1	-2	-2	-1	0

The average value for each cell of each group was used for the MDS procedure.

Each cell of each participant's difference matrix was compared using t tests.