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ABSTRACT

This paper describes the characteristics of graphic techniques, such as networks, pattern notes, semantic maps, and graphic organizers, that can be used to acquire knowledge of relationships between concepts in a content area. The implications for research and instructional design are considered, and nine types of these techniques are described and illustrated. A model that proposes different effects of these graphing strategies based upon the cognitive processes required to construct the graphic is presented. Hierarchically organized graphics require analysis and elaboration of content and seem to enhance recall and transfer of learning. Heterarchical graphics require integration of content, which facilitates inference and problem-solving. While other characteristics of graphic techniques may affect learning outcomes, the primary differences will result from the types of cognitive processes induced when the graphics are generated. (Contains 36 references.) (KRN)

Title:

Using and Selecting Graphic Techniques to Acquire Structural Knowledge

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Using and Selecting Graphic Techniques to Acquire Structural Knowledge

Abstract

Structural knowledge, the knowledge of relationships between concepts in a content area, is essential for comprehension and problem solving. One method of assisting learner in acquiring structural knowledge is through the use of graphic techniques as learning strategies. Graphic techniques, such as networks, pattern notes, semantic maps and graphic organizers, are two-dimensional diagrams of conceptual relationships. In this paper the characteristics of graphic techniques are described, and the cognitive processes used to construct the diagrams are proposed. We propose a model for selecting between different graphic techniques based upon the cognitive processes elicited by the technique, and the learning outcomes derived from these processes.

Structural knowledge is knowledge that represents the relationships between concepts in a content domain. While structural knowledge may be conveyed in a number of ways, recently there has been an increased interest in techniques that display structural knowledge through graphic depictions of the relationships between concepts. This paper is based upon the premise that when different graphic techniques are used as learning tools different cognitive processes are elicited, resulting in different learning outcomes. The purpose of this paper is twofold. First we describe the value of conveying structural knowledge and the use of graphic techniques to convey this knowledge. Second, we present a model which describes differential learning outcomes of a variety of graphic techniques based upon the technique's attributes and the types of cognitive processes that are elicited when the graphics are constructed.

Structural Knowledge

Structural knowledge is an important construct in learning and instruction for several reasons: 1) structure is inherent in all knowledge, 2) structural knowledge is essential to comprehension, 3) learners acquire structural knowledge as a natural outcome of instruction, 4) experts represent structural knowledge differently from novices, and 5) structural knowledge is essential to problem solving.

1) Structure is inherent in all knowledge. "Meaning does not exist until some structure, or organization, is achieved" (Mandler, 1983, p. 4). Without structure, mental constructs could not be formed, because nothing could be described. The more abstract the ideas are, the more important structure becomes.

2) Therefore, structural knowledge is essential to comprehension. We naturally and necessarily organize our mental representations of phenomena in order to be able to access them. Structural knowledge has greater importance as the task increases in complexity. For instance, meaning for text evolves from story schemas (structures) that readers construct by integrating them with exisiting knowledge structures. Bruner (1960) believed in the need to teach students how ideas or concepts within a content area are linked, arguing that failure to learn this structural information results in an inability to comprehend ideas and transfer them to new situations. Acquiring knowledge about the structure of a content area allows learners to better comprehend and retain content and apply it to new situations. Bruner believed that "knowledge one has acquired without sufficient structure to tie it together is knowledge that is likely to be forgotten" (Bruner, 1960, p 31).

3) Learners acquire structural knowledge as a natural outcome of instruction. As instruction progresses, the learners' conceptions of content (including structure) become more interrelated and correspond more closely with the teacher's content structure (Shavelson, 1974). So learners acquire structural knowledge, as well as declarative and procedural knowledge, from instruction.

4) Experts represent structural knowledge more efficiently and effectively than novices. Among the major differences between experts and novices is that experts' knowledge includes rich sets of pattern-indexed schemata that guide problem interpretation and solution (Larkin, McDermott, Simon, & Simon, 1980). These schemata are the expert's structural knowledge about his/her field. Experts develop more elaborate schemata and these richer schemata involve more complex structures that enable them to reason more effectively.

5) Structural knowledge is essential to problem solving. A number of research studies have demonstrated the importance of structural knowledge to problem solving (Chi & Glaser, 1985). The extent to which problem solving protocols contained relevant structural knowledge is the strongest predictor of how well learners solve transfer problems in

physics (Robertson, 1990). Domain-specific problem solving relies on adequate and appropriate knowledge structures.

The acquisition of structural knowledge is integral to recall, comprehension, and transfer. Structural knowledge provides a semantic foundation for the comprehension of materials and solution of domain-specific problems. Therefore, it is important to facilitate the construction and acquisition of structural knowledge during learning. One approach to facilitating structural knowledge acquisition is the explicit elicitation and communication of structural knowledge during learning and instruction. That is, knowledge structures are elicited from experts or experienced practitioners and mapped onto instructional materials. This mapping may be implicitly conveyed in the organization of the content or graphically depicted for the learner.

Graphic Techniques

Graphic techniques are spatial representations of structural knowledge in a content area. As noted above, these representations can be developed by experts and provided to learners to promote acquisition of structural knowledge. However, the purpose of this article is to examine the use of graphic techniques as learning strategies drawn by learners as they study material from texts, lectures, films and other media. Although each of the techniques can be used to depict structural knowledge, they differ from each other in appearance, types of relationships displayed, and the use and type of labels used to name concept relationships.

Appearance

The most obvious difference between graphic techniques is the format and appearance of the end product. Some types of graphics use a matrix format, others have lines connecting concept words, and another uses box-like frames sectioned into further squares and rectangles. The actual appearance of these graphics has little to do with their effectiveness in representing structural knowledge; however, those strategies with more complex appearances may be more difficult to learn or to interpret.

Types of Relationships

The number and types of relationships that are depicted by each technique also differs. Some convey hierarchical information in which concepts are subsumed by broader, more inclusive concepts. While this hierarchical information is a component of content structure, it depicts only a limited representation of that structure. Other spatial strategies permit the representation of a broader variety of relationships and interrelationships between concepts. This depiction of multiple interrelationships between concepts is referred to as a heterarchical structure.

Labelling

Some graphic techniques use no labels so that the relationships between concepts are not clearly defined. While the learner may mentally identify the type of relationship between concepts when developing the graphic representation, these relationships are not explicitly identified on the product. When multiple relationships are depicted confusion regarding the type of relationship between concepts may arise if no labels are used. The strategies that use labels to identify the type of relationship that exists between concepts may allow the learner to create their own labels, or use a predefined set of relationship types.

The type of labelling system has some impact upon the usefulness of the technique. If one attempts to represent a content area with an insufficiently inclusive labelling system, misinterpretations of the final product may result. On the other hand, those strategies which use prespecified labels require the person drawing the map to identify not only the concepts, but also the relationships between those concepts. An additional analysis is necessary to fit the relationship label into a prespecified taxonomy. There is some evidence that this extra processing requirement may be beneficial to learners. Holley and Dansereau (1984) reported that when a modified form of networking using learner-generated labels was field tested, learners with high verbal ability benefitted from the networking strategy, but learners with low verbal ability did not. Low verbal ability learners showed greater retention and recall of content when they used prespecified labels of relationships.

While the appearance of the graphic and the use of labels to identify relationship type may impact learning, the most important difference between representational strategies appears to be the types of relationships depicted. More specifically, it seems that the primary difference in learning outcomes is dependent upon whether the representations are strictly hierarchical or if they allow for depiction of multiple (heterarchical) relationships.

Graphic techniques used as learning tools include semantic maps, semantic features analysis, spider maps, structured overviews, pattern notes, concept maps, networks, text maps and schematizations. In the following section each of these representations are described in terms of the three attributes described above.

Types of Graphic Learning Tools

Graphic techniques that utilize a hierarchical structure vary in their visual format--using linear, matrices, or web-like representations. The ***structured overview*** (later renamed *graphic organizer)* uses a linear representation in which the most important topic of a passage or a lesson is listed at the top, with important sub-topics presented underneath, and further sub-topics for each of them listed next (Barron 1969, 1980). The organizer continues until all of the important ideas are included on the graphic. Thus, hierarchical relationships between terms are shown through the use of unlabeled lines (see Figure 1 for example).

Insert Figure 1 about here

The ***semantic features analysis*** is another hierarchical graphic technique that that utilizes a matrix rather than lines to depict relationships (Johnson, Toms-Bronowski, and Pittleman, 1982; Johnson, Pittleman, Toms-Bronowski, Levin, 1984). In order to perform this technique, the general topic of instruction is selected, and words related to the topic are identified and listed in a column (see Figure 2 for example). Then features shared by some or all of the words are listed in a row across the top, forming a matrix. Next, learners indicate whether each concept has each of the features by putting a "+" or a "-" in each of the boxes corresponding to the concept and the feature.

Insert Figure 2 about here

Semantic maps and ***spider maps*** use a web-like format rather than a linear structure. ***Semantic mapping*** (Johnson et al, 1982; Pittleman, Levin, and Johnson, 1985; Johnson et al, 1984; Heimlich and Pittleman,1986) is relatively simple. A general topic is defined and written in the center of a piece of paper (or chalkboard).

Then concepts that are related to the main topic are identified and connected around the main topic in a web-like fashion with unlabelled lines. Examples of these secondary concepts are identified and simply listed beneath these concepts. Thus, a three-tiered hierarchy of concepts is generated and graphically represented. (See Figure 3 for example).

Insert Figure 3 about here

A *Spider Map* is a graphic technique developed by Hanf (1971) as an alternative to traditional notetaking from text. In spider mapping, the main idea of the text passage is written in the center of a page, and related, subordinate concepts are drawn on lines connected to the central idea (see Figure 4 for example). Additional lines with increasingly detailed content can be added to the drawing, with the end product resembling a spider web.

Insert Figure 4 about here

The next group of spatial techniques utilizes interrelational, heterarchical representations. Examples of this technique include pattern notes, concept maps, semantic networks, schematization, and text maps.

Pattern notes, a technique very similar to spider mapping, was developed originally as *brain patterns* by Buzan (1974) and subsequently retermed *pattern notes* (Fields, 1982; Jonassen, 1984, 1987) (See example in Figure 5). Like spider maps, pattern notes are drawn in a free-flow, unconstrained manner. The pattern note is created by writing the main topic on the center of a page, with a box drawn around it. Then related ideas are drawn on lines connected to the center box. Additional lines and ideas are added, forming multiple layers around the central idea until all of the important ideas about the topic have been included on the note. A final step in the pattern noting process, which distinguishes this technique from spider mapping, is to draw additional lines linking ideas to show interrelationships between concepts.

Insert Figure 5 about here

A modification of pattern notes was developed by Jonassen (1984) to allow for labelling of relationships between concepts. Without labels, pattern notes can be difficult to interpret, as one cannot be certain of the type of relationship represented by the connecting lines. Thus, strategies that include labels of the relationships can be helpful in clarifying content structure. *Labelled pattern notes* use predefined symbols to depict the relationships that exist between concepts.

Concept maps (Novak and Gowin, 1984, Novak, 1980, 1981; Stewart, Van Kirk and Rowell, 1979; Stewart, 1984) consist of concepts, or "nodes" linked by labeled lines to show relationships and interrelationships between terms. Unlike pattern noting, in concept maps the concepts are arranged hierarchically, so that the most inclusive, subsumptive concepts appear at the top of the map, with less inclusive, subordinate concepts below (see example in Figure 6). Like pattern notes, heterarchical relationships between concepts are depicted by lines. Here, labels of the relationship type are simply words selected by the learner, rather than symbolic labels representing a fixed set of relationship types.

Insert Figure 6 about here

Networking (Dansereau, 1978; Dansereau, Collins, McDonald, Holley, Garland, Diekhoff and Evans, 1979; Dansereau and Holley, 1982; Dansereau, McDonald, Collins, Garland, Holley, Diekhoff and Evans, 1979; Holley and Dansereau, 1984) is a text mapping strategy developed as part of an overall study strategy. To create a network one first identifies the key concepts in a subject area, and then displays the interrelationships between these concepts using labelled lines (see example in Figure 7). Currently, networking employs six linkages which describe the relationships between concepts: "part of," "type of," "leads to," "analogy," "characteristic," and "evidence" (Holley and Dansereau, 1984). The first letter of each of these links is used to depict the type of relationship between concepts.

Insert Figure 7 about here

Schematizing (Mirande, 1984; Camstra & Van Bruggen, 1984) is another technique that uses concepts representing main ideas linked to other concepts via symbolic labels. Rather than specifying precise concept relationships the labels used in schematizations are: dynamic relationship, static relationship, similarity, interaction, and the negation of these four types of relationships. These relationships are symbolized by different types of lines linking concepts. Plain lines, lines with arrows at one or at both ends and double lines are used between concepts on schematizations. Schematizations include "specifications lists," which are lists and definitions of each of the concepts used in the schematization graphic (see Figure 8 for example).

Insert Figure 8 about here

Anderson (1979) and Armbruster and Anderson (1984) developed ***text maps*** as a technique to allow students to link ideas together and show their relationships. Maps consist of a general organizing structure, referred to as a frame. Within this frame learners map the relationships between ideas using symbols to represent seven different types of relationships that can exist between two ideas, or two special relationships which define or highlight the importance of a concept (see Figure 9 for example).

Insert Figure 9 about here

Selecting Appropriate Graphic Techniques: A Model

Selection of a graphic techniques to enhance learning should be based upon the desired performance outcomes. When examining the different effects and outcomes of these techniques it is helpful to consider the cognitive processes and strategies that are elicited when the representations are generated. We propose that different cognitive processes are induced by the cognitive strategies undertaken when creating the graphic. Cognitive processes are the manner of thinking and associating ideas, including analysis, elaboration, and integration of information. Cognitive strategies are the specific mental manipulations of information that are undertaken as part of the cognitive process. These in turn produce different effects and result in learning at different levels of cognitive performance. This model for selecting appropriate graphic techniques interrelates the cognitive processes of the various spatial representations with cognitive effects and performances, and is presented in Table 1.

Insert Table 1 about here

Cognitive Processes and Strategies

As noted previously, we propose that the most important characteristic of graphic learning techniques is whether they represent hierarchical or heterarchical relationships. Further, we propose that this difference is important because the development of hierarchical and heterarchical graphic techniques elicit different cognitive processes.

Analysis and elaboration are the types of cognitive processes that are used when developing hierarchical representations, such as semantic maps, semantic features analysis, structured overviews, and spider maps. Analysis is the breaking down of concepts into component parts, and the organization and categorization of those parts. This type of cognitive process is used in making all of the representations, but is particularly evident in the representations which have hierarchical formats. For example, note that the semantic map shown in figure 3 breaks down the large concept of "music" into important subordinate concepts, and further analyzes by identifying organizing those concepts into groups, and categorizing them.

The second type of cognitive process used in generating graphic techniques is elaboration. Elaboration is relating new knowledge to prior knowledge. There are three elaboration strategies that can be used when generating these graphic techniques: paraphrasing material, using imagery to picture new material in familiar contexts, and generating examples of new ideas from prior knowledge.

Heterarchical representations include concept maps, pattern notes, text maps, networks and schematizations. These representations use both analysis and elaboration but also allow for a third cognitive process: integration. Integration requires the learner to draw relationships between pairs of ideas from a new content domain. Integration can be accomplished by simply identifying interrelationships between the concepts displayed in the graphic. Alternatively, generation of analogies and/or metaphors requires the learner to consider the interrelationships between new ideas and relate these new ideas to prior knowledge.

Effects and Outcomes of Graphic Techniques

When considering the effects of graphic techniques it is helpful to frame the effects in terms of learning outcomes. One taxonomy of learning outcomes is provided by Component Display Theory (CDT) (Merrill, 1983). In CDT there are three levels at which concepts, principles or procedures can be learned: simple recall is referred to as the "remember" level; application of content is at the "use" level; and discovery of new concepts, principles or procedures requires that one "find" new knowledge.

We propose that learning tools that require analysis promote recall of content. Breaking "big" concepts into their component parts and organizing those parts should assist learners in remembering concepts. Prior research has indicated that categorizing ("chunking") concepts based upon similarities promotes recall of those concepts. Therefore technique of analysis seems most helpful in promoting recall of content, which would allow learners to perform at the "remember" level of learning.

Elaboration strategies are an important part of learning because as new information is linked to prior knowledge it becomes imbedded in existing knowledge structures, making it easier to recall and use the information. Mayer (1980, 1988) found that elaborations enhance learners' ability to transfer learning to new situations. In particular, it seems that elaborations such as paraphrasing and exemplifying are helpful in near transfer tasks in which the learning task is similar to those tasks presented in learning materials. In CDT terminology, ability to transfer learning to new problems in familar contexts requires learners to "use" that information. Since elaboration techniques are also helpful in recalling information, this model for selecting graphic techniques predicts that elaboration strategies would enhance learning at both the "remember" and "use" levels.

Since heterarchical representations incorporate both analysis and elaboration, recall and transfer of learning are facilitated when these techniques are used. In addition, integration of information helps to improve a learner's ability to draw inferences based upon that content (Mayer 1980, 1988). Inference is an important component of problem solving, and is requisite for learning at the "find" level.

To use this model for selecting between the various graphic techniques first consider the type of instructional outcome desired. If the objective is simply to recall the content at a later date appropriate graphic techniques would be hierarchical. If one must recall the content and be able to apply the knowledge to new situations transfer of learning is required. In this case hierarchical techniques are appropriate, but learners should be encouraged to elaborate when developing the graphic. Finally, if learners are expected to creatively solve problems after completing instruction, appropriate learning techniques should require integration of concepts. Therefore, heterarchical graphic techniques would be most appropriate.

Summary

Structural knowledge is an important component of learning in any content area. Graphic techniques illustrate the relationships between concepts, thereby conveying structural knowledge. These techniques can be used as learning tools to assist learners in acquiring structural knowledge and enhancing learning outcomes.

This paper presented a model which proposes different effects of these graphing strategies based upon the cognitive processes required to construct the graphic.

Hierarchically organized graphics require analysis and elaboration of content, and seem to enhance recall and transfer of learning. Heterarchical graphics require integration of content, which facilitates inference and therefore problem solving. While it is possible that other characteristics of the graphic techniques may affect learning outcomes, it is our contention that the primary differences will result from the types of cognitive processes induced when generating the graphics. However, research is needed to validate this model of strategy selection. In addition, research into the differential effects of learning strategies for learners with different aptitudes will assist instructional designers in prescribing appropriate learning tasks to optimize performance.

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	Spatial Representation	Cognitive Process	Cognitive Effects	Cognitive Performance
Hierarchical	Stuructured Overview Semantic Map Semantic Feature Analysis Spider Map	Analysis Analysis Organization Categorization	Recall	Remember
		Elaboration Paraphrase Exemplify Imagery	Transfer	Use
Heterarchical	Concept maps Pattern Notes Text Maps Networks Schematizations	Integration Interrelate Ideas Create Analogies Create Metaphors	Inference	Find

Table 1. Model for selection of graphic techniques

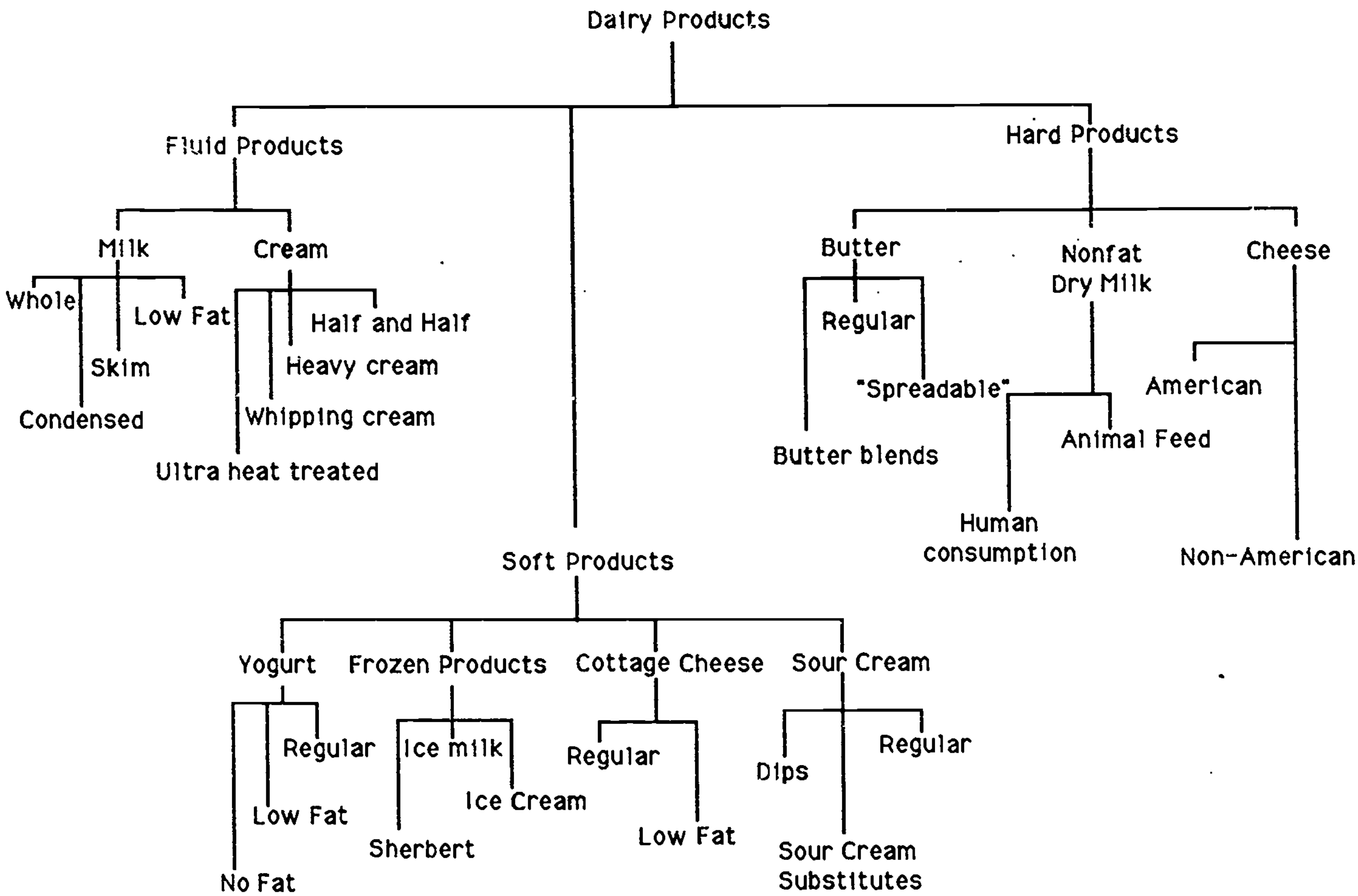

Figure 1. Structured overview

Forms of Government

	Economic Democracy	Political Democracy	Private Property	Dictatorship/Autocractic	Free Market	Welfare State
Communism	+	+	-	-	-	+
Socialism	+	-	-	+	-	+
Nazism	-	-	+	+	-	-
Capitalism	-	+	+	-	+	-

Figure 2. Semantic Features Analysis

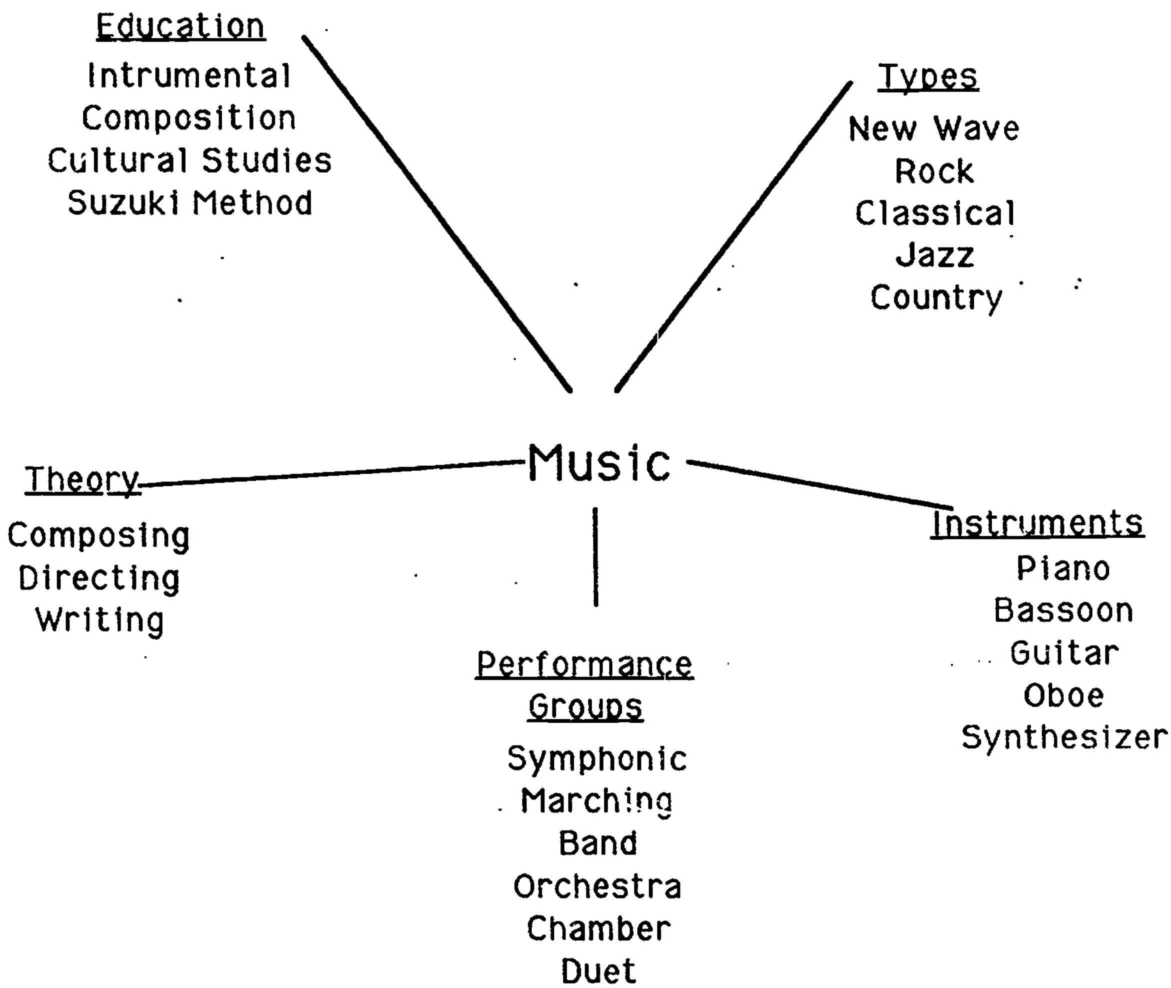

Figure 3. Semantic Map

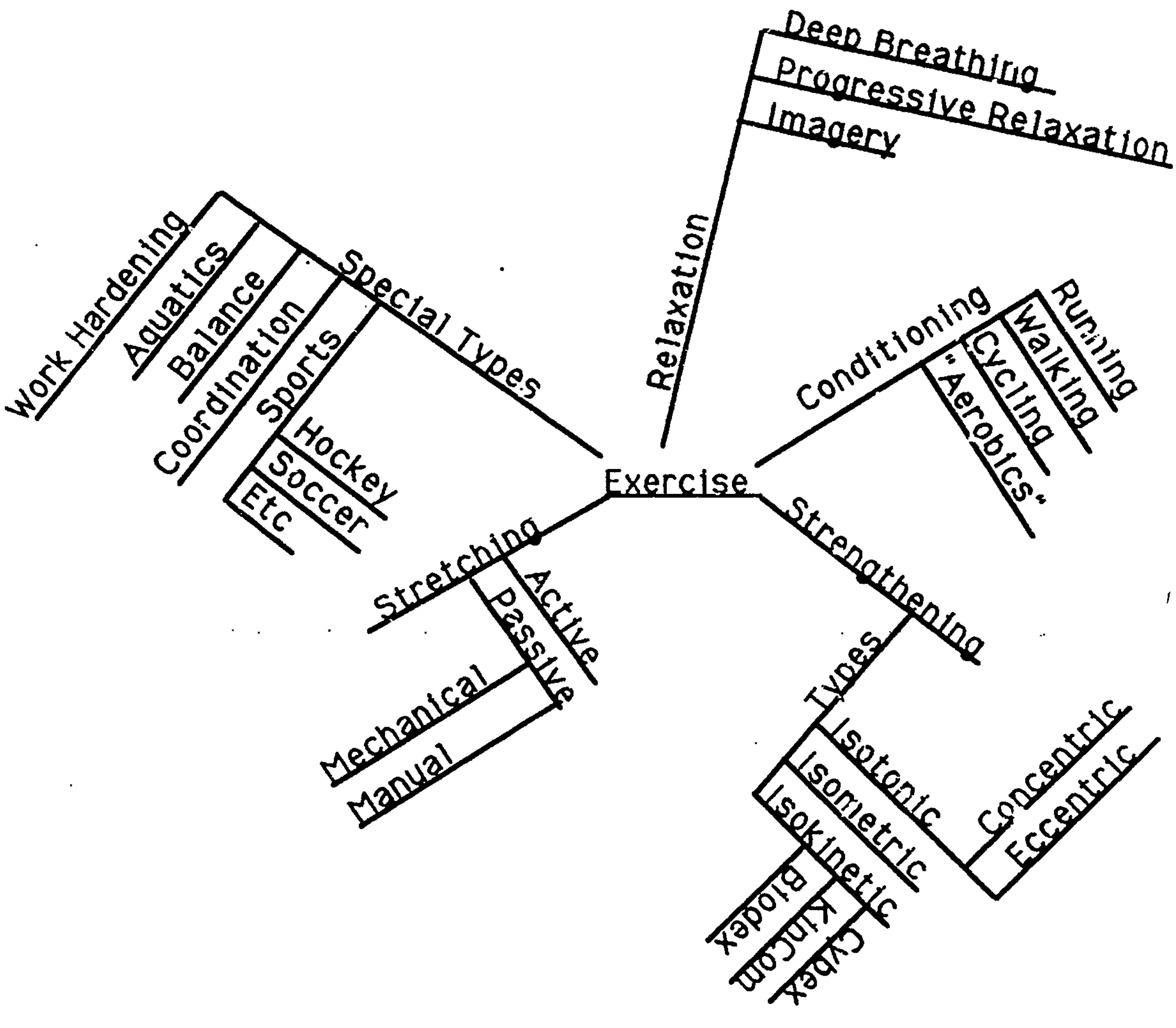

Figure 4. Spider Map

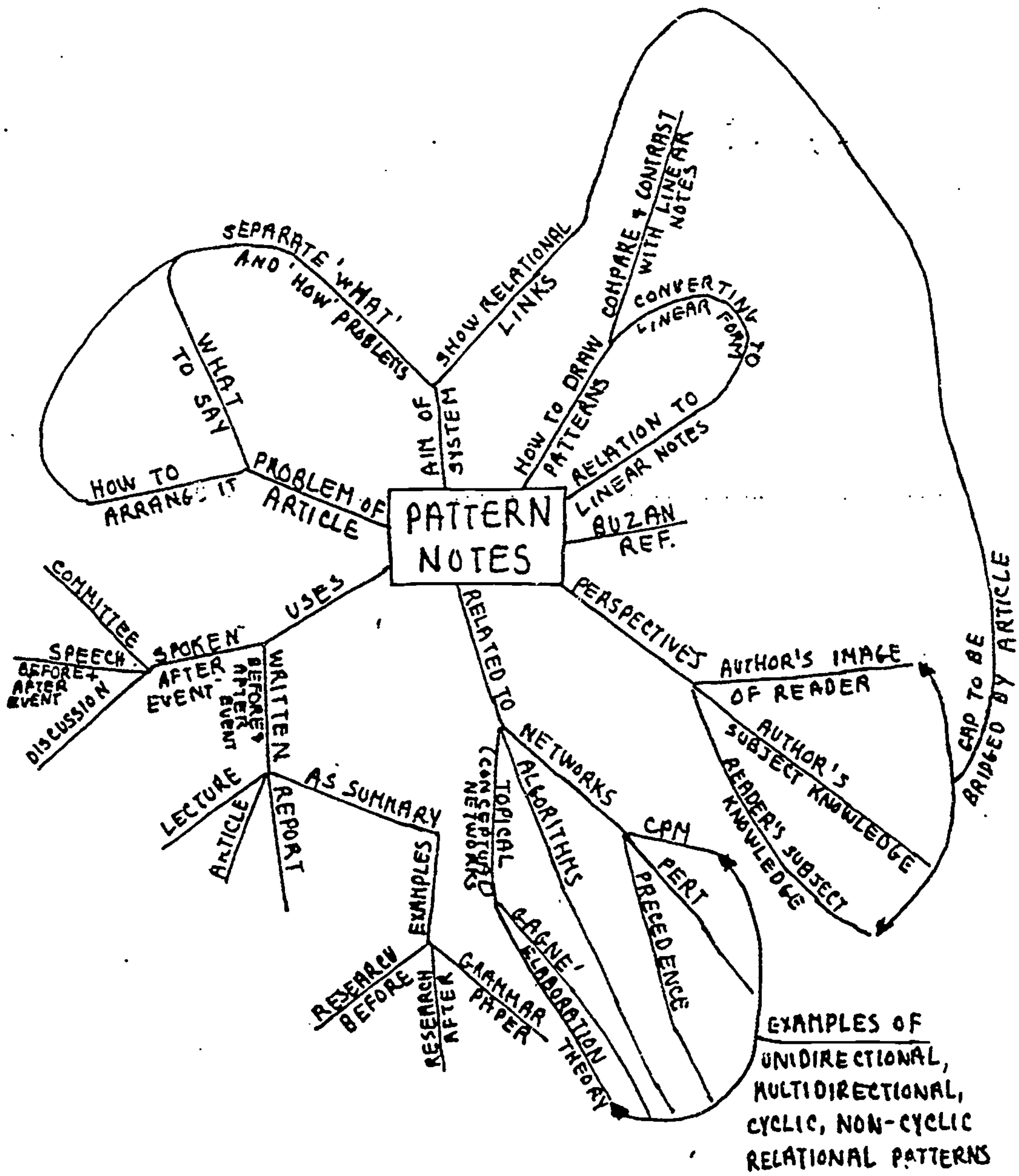

Figure 5. Pattern Note

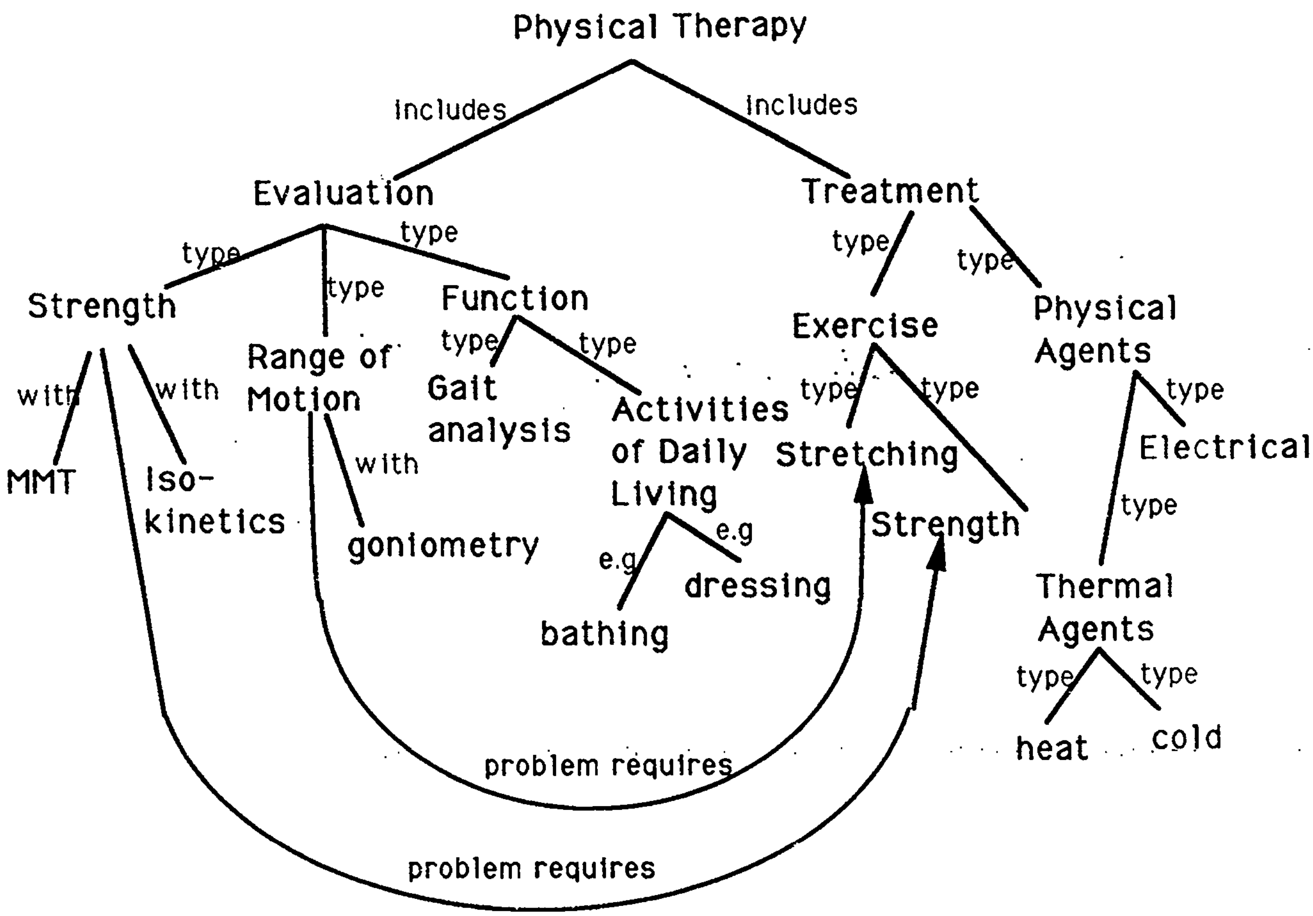

Figure 6. Concept Map

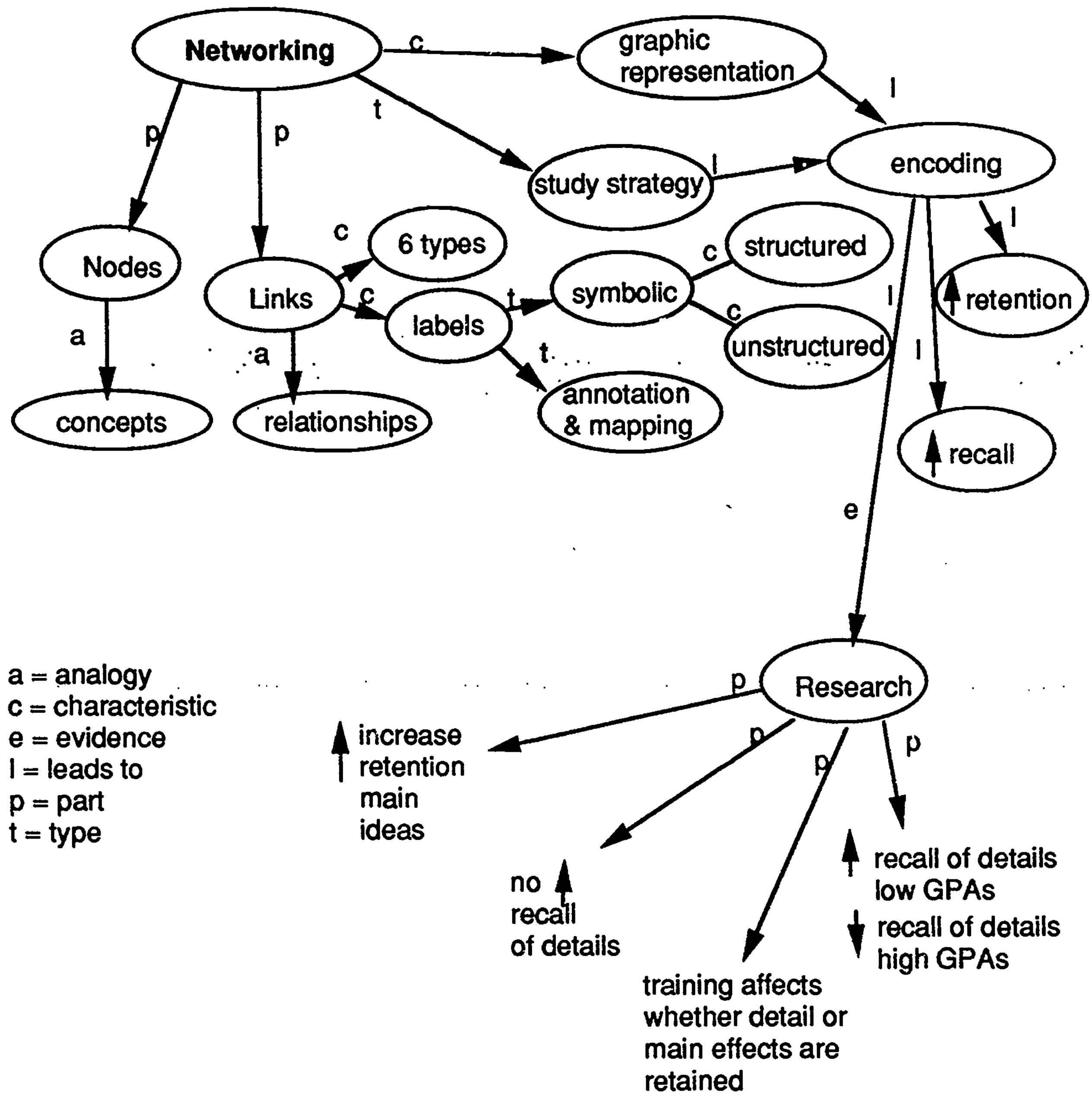

Figure 7. Network

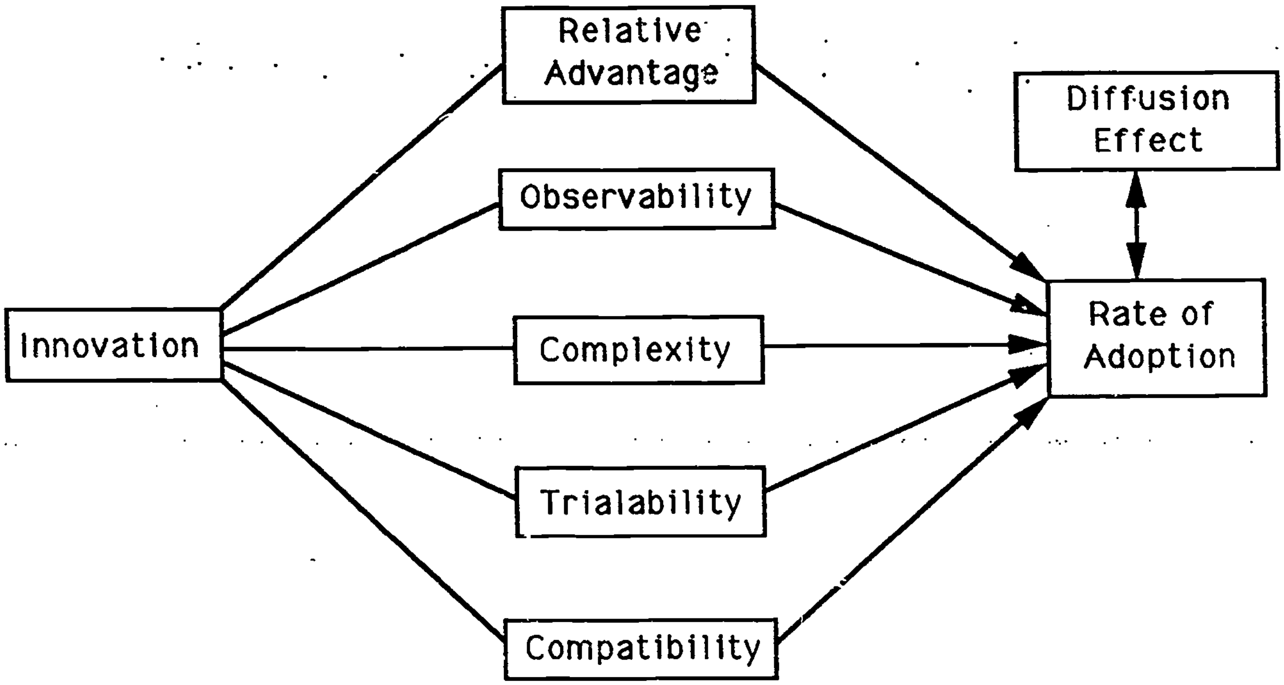

Figure 8. Schematization

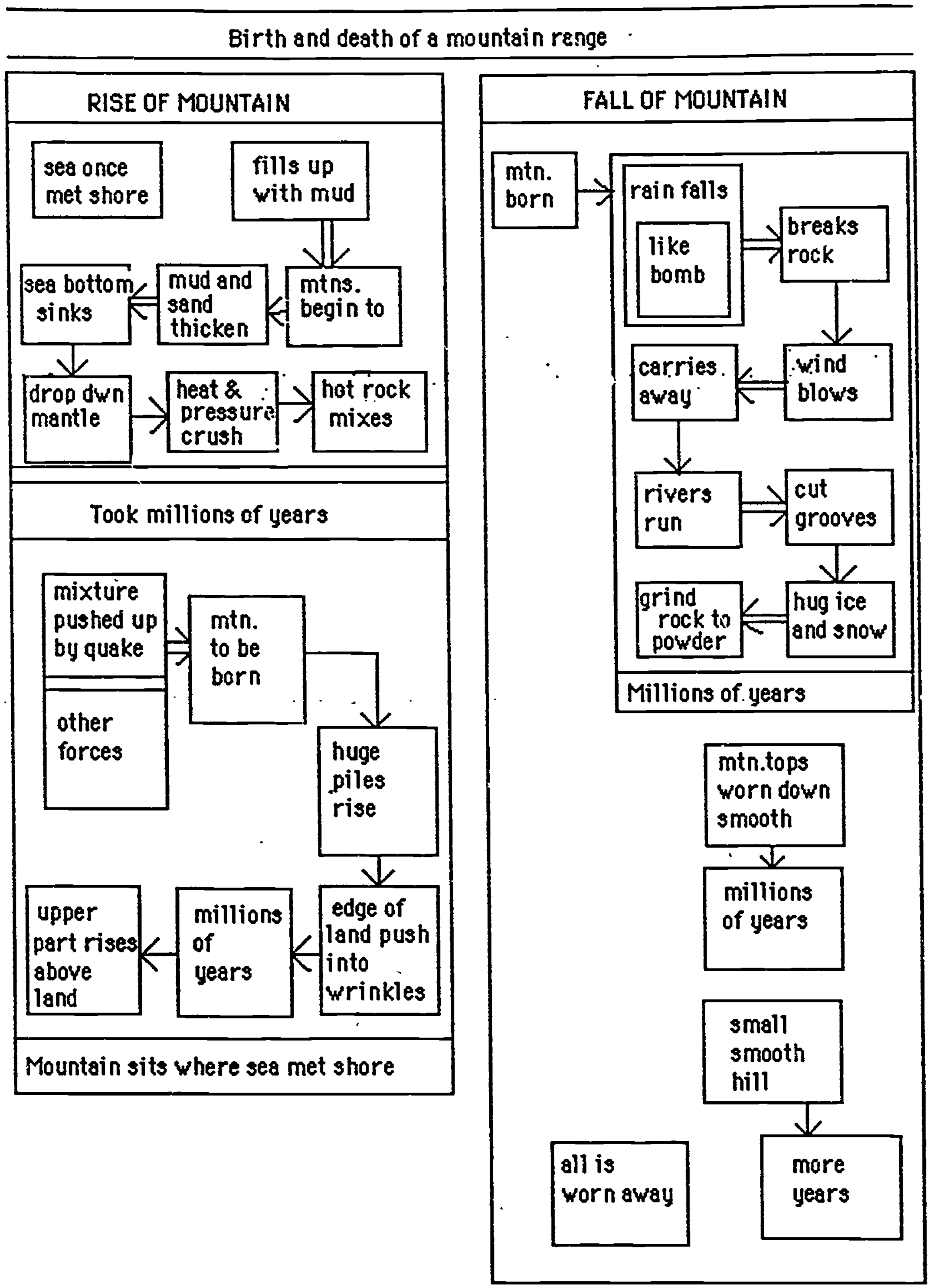

Figure 9. Text Map