TEACHING CONCEPTUAL NETWORKS[1]

Susan M. Markle
University of Illinois, Chicago Circle

There are some axioms of instructional design that I would like to state and have done with. The data at this point are so overwhelming that designers must abide by them.

Axiom 1: It is not what is presented to the student but what the student is led to do that results in learning.

Whether you choose to file this under "the active response principle" of old-time programed instruction (Markle, 1964), or under the effects of questioning on student retention in the more recent mathemagenic research tradition (Anderson and Biddle, 1975), or under the new interest in levels of processing in the most recent cognitive research (Klahr, 1976), the principle is axiomatic. One way transmission to passive audiences is passé in all media.

Cognition is back in favor in psychology, with burgeoning discussions and research on task structures, concepts, knowledge structures, and such. Our heads are getting full again. Out of this activity come the next two axioms. Axi-

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oms II and III are opposite sides of the same coin.

Axiom II: No concrete instantiation is an example of only one concept.

I demonstrate this axiom to my educational psychology class and to other groups by asking them to classify something with the first label that comes to mind when they see it.

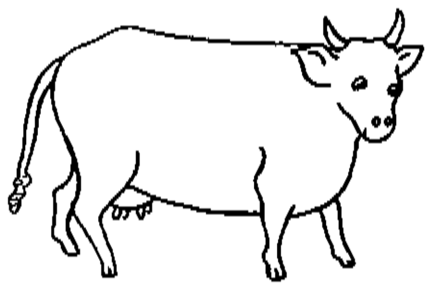

Figure One. An Elicitor of multiple classification responses.

The overwhelming first response is "cow." This kind of almost unanimous vote can be obtained with all sorts of visuals—there is a conventional level of labeling objects (Miller and Johnson-Laird, 1976), and few of us violate the convention when asked to give the first name that comes to mind. But this picture is an example of many concepts, not just "cow." When asked to classify it again, to give another label, most people will move up the hierarchy of labels that apply to this object, and say "animal." When asked to classify it yet again, the answers begin to vary, but almost all of them lie somewhere between the highly generic label "animal" and the more specific label "cow."[2] Responses include "farm animal", "mammal", "quadruped", and so forth. Noticeably missing from my undergraduate data are academic categories such as "ungulate." "Herbivore" turned up once. A smattering of responses elicited in this exercise are simply wrong—it is not a bull, and any farm boy can see it is not a heifer. Students who say "milk" are associating, not classifying; the picture is not an example of "milk". The final challenge is to change completely the semantic field (the frame of reference or universe of discourse) and go beyond these predictable animal kingdom names. Some stu-

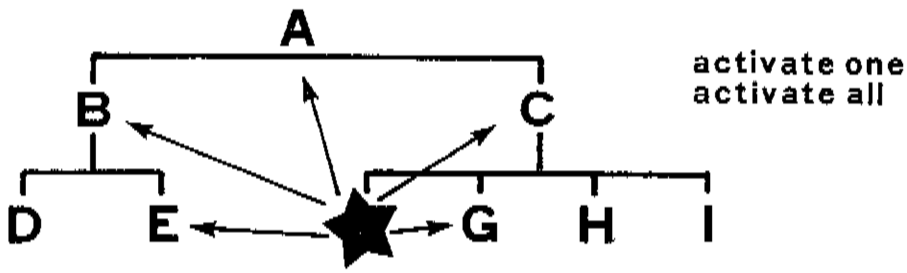

Figure Two. Activation of a conceptual structure.

dents can't do that, but I have had such insightful shifts of field as "asset" from economics, "stimulus" from psychology, and "line drawing", as well as "bad art." This single concrete example, therefore, can be used as an instantiation of many different concepts some of which are in no way related to each other.

Axiom III follows logically from such multiple class membership.

Axiom III: You cannot teach a concept with a single example.

The past few years of research on single concepts in respectable academic subjects has clarified the role of the rational set of examples as well as key kinds of nonexamples in fostering learning of these complex concepts. (Markle and Tiemann, 1969; Englemann, 1969; Tennyson, Woolley, and Merrill, 1972; Klausmeier, Ghatala, and Frayer, 1975.)

The role of the nonexample has changed in very recent research on the teaching of coordinate concepts—sets of concepts that belong together in a discipline and represent the same level of generality within the structure of the subject matter. (Olsen, Reigeluth, and Merrill, 1977; Tiemann, Kroeker, and Markle, 1977). In real subject matters, a nonexample of one concept is an example of another related concept. The label "horse" names a nonexample of "cow", a negative reinforcer is a nonexample of a positive reinforcer, and so forth. Students who have mastered the conceptual structure of a subject matter can name each coordinate concept, as well as being able to go up and down the hierarchy in which any one of them is embedded. Perhaps no one has captured the essence of this state of mastery more concisely than Miller and Johnson-Laird (1976). They say "When a language user masters his vocabulary, he organizes it into memory structures in such a way that whenever a particular concept in that structure is activated, the whole structure becomes activated and available to attention. It is as if every word in the structure were a part of the meaning of every other word." Figure Two illustrates such a hypothetical activation when concept F is activated.

Cognitive psychologists searching into our memory structures are more concerned with the organization of our storage systems as finished products and less concerned with how this structuring comes about. The problem for instructional designers is to find procedures for bringing such structures into being as efficiently as possible.

Using the all-time favorite example of what a concept is, the concept of "dog", let us embed it in a knowledge structure. It is a class that can be broken into several subsets, the names of the breeds, or into functional classifications such as "hunting dog". It is also a subset of many other concepts, such as "mammal" and "vertebrate" and "animal." These relations are hierarchical, within the animal kingdom. Some examples of "dog" may turn up in other semantic fields — such as "winner" at the race track, or

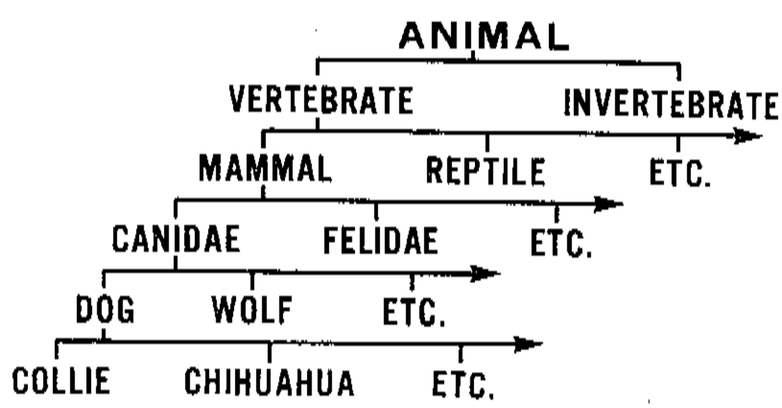

Figure Three. A part of the well-known hierarchy of the animal kingdom.

[2]The terms "generic" and "specific" refer to the relative size of the sets involved, with "generic" labeling the more inclusive set. Any example of "animal" is equally as concrete as an example of "cow". Thus, we are not dealing with abstract versus concrete, but rather with inclusiveness.

"means of transportation" in some cultures. Part of the knowledge structure that people acquire is the hierarchical structure of the animal kingdom, but "dog" occurs in other structures as well.

How do you build such a structure? If the learner has acquired the kind of visual literacy that would make a hierarchy diagram meaningful (Olson and Bruner, 1974), practice in classifying and reclassifying relatively concrete items — such as line drawings of cows, cats, squirrels, and so forth — would satisfy the processing requirements of my first axiom. If the learner does not have such diagramatic literacy, this intellectual skill could become a prerequisite to be taught first.

The same rational approach to selecting cases found in concept analysis techniques (Markle and Tiemann, 1974) can be generated in programing a learner through such a hierarchy. The appropriate learner activity is classifying cases in all applicable categories. As with test cases for algorithms, one simply checks that all or most pathways through the network have been covered by the student. Although many of us have made the point that reciting definitions does not provide evidence of concept mastery (Gagné, 1965; Merrill, 1971; Tiemann and Markle, 1973), I think verbalizing would be helpful here. Students should not only be able to classify an instance of a dog as both a mammal and a vertebrate but should also be able to state that all mammals are vertebrates.[3] In some ways, these knowledge structures are examples of Gagné's category of verbal information (1974) for which verbalizing is an appropriate outcome.

For instructional designers, these knowledge structures differ in key ways from the hierarchical structures illustrated in the work of Gagné and his colleagues (Gagné and Paradise, 1961; White and Gagné, 1974) and Resnick and her colleagues (Resnick, Wang, and Kaplan, 1973). A valid hierarchy of intellectual skills immediately locks an instructional designer into a sequential approach to teaching. Skills at lower levels must be taught first. No such locked-in sequencing is dictated by a knowledge structure. In the ordinary course of learning this animal hierarchy in the unplanned bombardment of preschool, youngsters acquire the concept of "dog" first, followed by "animal." The breed names might come next, while the more technical terms "mammal" and "vertebrate" are mastered in school. Order does not seem to matter.

A second key difference between the two kinds of hierarchies lies in the need for the designer to assure completeness. Many of my college students have never heard of the technical term "canidae" for the class immediately above "dog" but these students do not feel culturally deprived by this gap in their knowledge structure. Any professor of biology can, and usually does, further increase the complexity by adding intermediate sets to the progression shown here. A missing piece in a skills hierarchy can lead to disaster. Not so with a knowledge structure; it can stand at many levels of elaboration, with new pieces to be fitted in where they belong as knowledge grows.

A third difference between knowledge structures and skill hierarchies was presaged in Bruner's (1960) remark that concepts can be taught "effectively in some intellectually honest form to any child at any age." In a skill-hierarchy, a half-mastered skill is of no use in progressing to the next level of complexity, but in a knowledge hierarchy, a concept which has not been mastered to its fullest extent can still fall into place. So an instructional designer faced with such a knowledge structure has considerable leeway for creativity in sequencing within the hierarchy, in editing out unnecessary elaboration where technical distinctions are not needed, and in limiting the range of tangential concepts.

The animal hierarchy is so familiar that the complexity of getting the pieces fitted together may not be apparent. Piagetian scholars tell us that beyond a certain stage of intellectual development, the logic of such hierarchies is known to youngsters. Class inclusion and multiple classification have been mastered. But a student confronted with an unfamiliar subject matter is in the same position as a youngster confronting this earlier material. In my educational psychology classes, the first topic is behavior modification in the classroom. The knowledge structure that lies behind the behaviorist school generates a hierarchical scheme for environmental events.

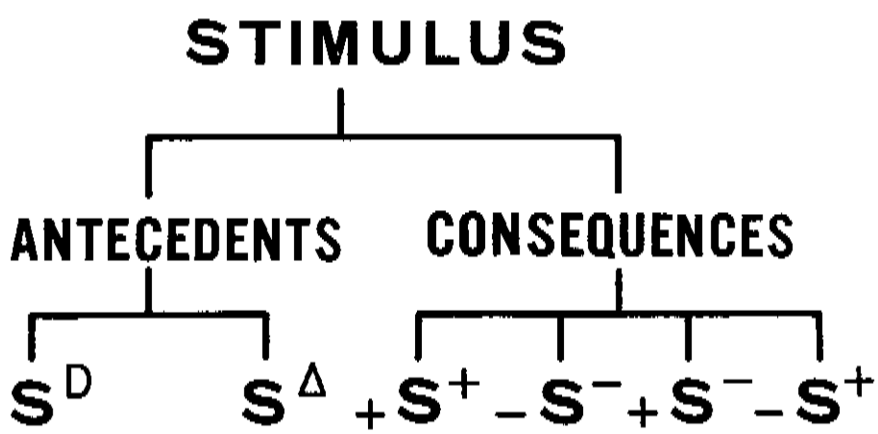

Figure Four. Classification structure of environmental events in behavior modification.

[3]An exhaustive classification exercise requiring learners to classify as mammals and vertebrates every specific subset of mammals known to them would be exhausting. Not only would such an exercise be excessive, but also it would not prove the rule. The danger of inducing such a rule from what is known can be easily demonstrated by considering the relation between "dog" and "pet." If learners do not know of wild dogs, they could erroneously conclude that "dog" is a subset of "pet" — that all dogs are pets, although not all pets are dogs. In selecting cases for students to consider, the designer, of course, can ensure that such erroneous conclusions are made untenable. A student who has verbalized the class inclusion rule "All mammals are vertebrates" should be able to apply it in the future. Confronted with a totally new esoteric species from some far-off land, the whole structure would "become activated," as implied in Figure Two above.

The generic term "stimulus" can be subdivided into "antecedents" and "consequences" of a particular behavior, and each of these intermediate categories can be further subdivided by subject matter experts in ways mystifying to students. Mastery of the lower level concepts can be measured by classification and principle-applying exercises. In the past two years, I have asked a delayed question on this material immediately before showing a film on Piagetian multiple classification tasks. In the film, a child, confronted with pictures of four ducks and two songbirds, is asked "Are there more birds or more ducks?" Being young, the child says there are more ducks. I ask my students to look at the classification scheme they learned earlier (the lowest level in Fugure Four, including only the two antecedents and the four consequences) and answer the parallel question "Are there more stimuli or more consequences?" At least half will reply that there are more consequences — four, of course. The subject matter structure has not come through although the lower level concepts have been sorted out and mastered.[4]

In this subject matter, as in many others, the concepts may be grouped differently when the topic changes. Skinner is known for his arguments against the use of aversive control (1954). The concept of aversive control as a superordinate rearranges the grouping of the earlier hierarchy into a new configuration, moving one of the reinforcers into the same set with the two punishers.

For students to understand this change, I ask them to work it out themselves on the basis of what they know about the properties of the four consequences. Telling them the answer does not make the point.

[4]There is more than one explanation for this finding in many subject matters. It is simple to show that many textbooks leave these coordinate relationships implicit, treating one of the concepts in one chapter and others in another. Students rarely get them together. The phenomenon noted with the "cow" example, the typical labeling level, is also a factor in this case. As with the Piagetian "duck" example, a reinforcer is usually called just that, rather than being called a stimulus, even though it is typically symbolized with an S. Further, in lay terms, a stimulus is an antecedent of a response, much as the childish concept of "animal" includes only a limited set of furry mammals.

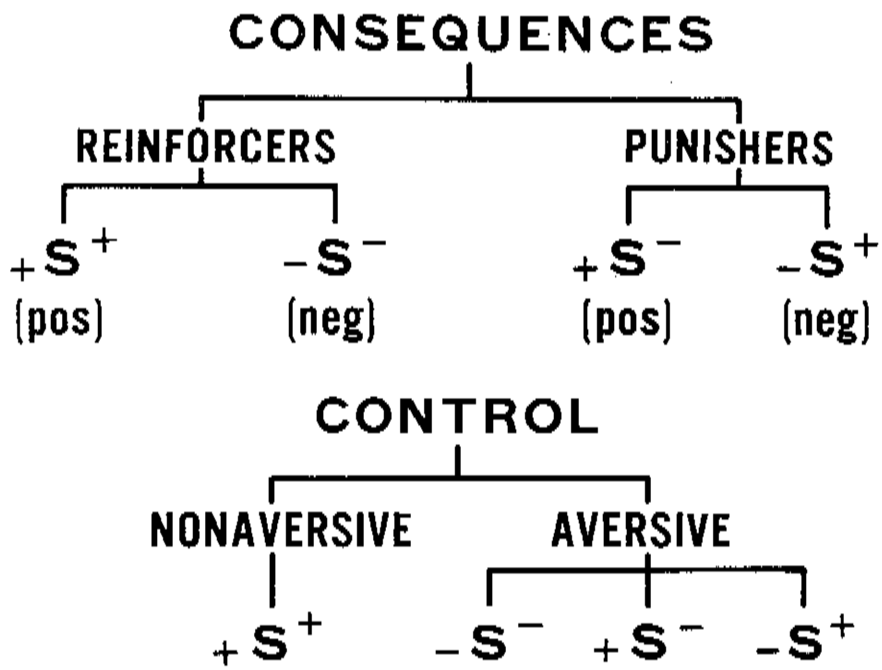

Figure Five. Shifting hierarchical organization of the same concepts in different topical fields.

Piagetian ideas are becoming popular in discussions of how to teach physics, (Griffiths, 1976) and similar phenomena have been noted in that discipline. The knowledge structures ingrained in subject matter experts are not yet available to beginners, even though these beginners are adults who have achieved the highest level of intellectual development in manipulating common knowledge structures such as the animal hierarchy.

Memory researchers (Collins and Quillian, 1972) have demonstrated some intriguing relationships between such hierarchical structures assumed to be in our memories and the response time for confirming or denying propositions which state various properties of various classes. They assume that we know that animals breathe, that birds are animals, and that canaries are birds. College students take longer to determine whether the sentence "Canaries can breathe" is true than to determine whether the sentence "Canaries can sing" is true. The property of breathing is filed high up in the hierarchy, with our concept of "animal", while singing is very much connected with songbirds such as canaries. What does this mean to instructional design, if anything? It suggests that most of us have been given insufficient practice in manipulating the knowledge we have on file. Designers should put more emphasis on deliberate training in flexible thinking, being fully aware that an instructional sentence such as "Animals breathe" is not likely to generalize automatically to all the cases to which it applies. As with the general principles for leading students to full mastery of a single concept, rational planning to cover a rich variety of cases will be required in making the knowledge that is filed in such hierarchical structures available to students when needed.

The importance of facility in negotiating the pathways up and down such structures is suggested in some recent research on problem solving. Landa (1976) in a chapter entitled "He couldn't figure it out because he couldn't figure it out" described the difficulty Russian students have with geometric proofs. When a particular figure is classified in one way, dredging up one approach to the problem, the learner is unable to shift levels of classification which might suggest another approach, although it can be shown that the learner does know the appropriate principles. Those principles are simply filed elsewhere in memory and are not, in the words of Miller and Johnson-Laird, "activated" when one level of the memory structure is activated by the way the learner classifies the figure in the problem.[5] Jill Larkin (1977) has observed a phenomenon of a similar nature in her investigations of the difference between subject matter experts and novices when confronted with a physics problem to be solved. As with Landa's geometry students, Larkin's novices knew the appropriate principles, but their approach to the problems differed from the experts in the amount of time it took novices to retrieve the information relevant to the problem. When problems move beyond the ordinary algorithmic types which can be immediately classified as requiring one or another procedure that a learner has mastered, the knowledge structure underlying the discipline becomes an important factor in success. Our job will be to find these structures in various subject matter areas and to redesign materials so that they become more accessible to beginners in a new discipline.

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[5]Although I have not collected data from whole classes, this phenomenon should be readily demonstrable in the college population. Confront such a population with a figure which is clearly a square and ask a group to classify and reclassify as was done with the figure of a cow. A square is a square is a square. From other less direct measures, I have data indicating that a square is rarely seen or labeled as a rectangle (an equilateral subset of that class), and is only with difficulty accepted as a parallelogram (having four sides with opposing sides parallel, it surely is an example of the latter class). The animal hierarchy which is favored by memory researchers is far more a part of common knowledge than are hierarchies from more academic areas.

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