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Network Representation of a Child's Dinosaur Knowledge

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A young child's knowledge of 40 dinosaurs was elicited from two tasks. The data gathered from these knowledge-production protocols were used to map two interrelated semantic networks of dinosaurs, viewed as concept nodes connected by links. The two mappings corresponded to two sets of dinosaurs (20 each), partitioned on the basis of external criteria: mother's subjective judgment of the child's knowledge of each dinosaur and the frequency of mention in the child's dinosaur books. Comparisons of the structure of the two mappings were based on three attributes: (a) number of links, (b) strength of links, and (c) the internal cohesion of the network in terms of higher order groupings and specific patterns of interlinkages. The validity of the differential structures of the two mappings was verified by the corresponding differential memory performance. The better structured set of dinosaurs was more easily remembered and retained by the child over a year than the less structured set of dinosaurs.

More and better structured knowledge has been a pervasive concept generally used for interpreting better memory performance. In the traditional list-learning literature, it has long been known that within an age group, the more knowable a list is, the better the recall. However, the literature on verbal learning is generally not explicit about what *knowable* means other than that it can be indexed by a number of measures, such as familiarity, meaningfulness, imagery values, frequency, and so on.

The term *more knowledge* has also been used as an explanation of better memory performance of individuals with greater skills. For example, chess experts can recall a greater number of pieces from a chess position than novices, and this ability has been related to the size of their knowledge base for chess patterns as well as the size of each pattern (Chase & Simon, 1973). That is, the expert has many more patterns or chunks that he or she recognizes, and the chunks also contain more pieces. Hence, skill differences in the domain have been attributed to a difference in the quantity of knowledge and not differences in the way that chess patterns are represented. Both the expert and novice players' knowledge of chess can be represented in the same way, namely, chunks or units of knowledge unified by relations such as color, proximity, locations, and so on (for more details, see Chase & Chi, 1981). Also, the structure of the representations may differ between experts and novices in that the configurations of their patterns may be different. However, because the exact nature of the experts' and novices' patterns is not specified, it is not clear whether the novices' knowledge base is deficient in (a) having fewer total number of patterns, (b) having smaller patterns, (c) having patterns with different configurations from those of the experts, or (d) all of the above.

Recently, the same interpretation has been used by developmentalists to explain memory performance differences between age

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groups (Chi, 1976, 1981; Dempster, 1978; Lindberg, 1980). It has been shown that a child's poorer memory performance, when compared with adults', may reflect in general his or her lack of knowledge. However, the deficiency in children's knowledge is usually not specified in an exact way, or else it is specified in the same way as the chunk structures discussed by Chase and Simon (1973; see Chi, 1978). Again, age differences, like skill differences, are attributable to a difference in the quantity of knowledge, and references to structural differences in the knowledge representation are made only in a global way.

By structural differences, we do not mean that there is a change in the representation of knowledge, as other developmentalists have done. In the developmental literature, the term *structural change* is often equated with the term *representational change*. That is, a representational change is often conceived of as the availability of new structures (Fischer, 1980; Halford & Wilson, 1980; Piaget, 1970). Keil (1981), for example, refers to "radical restructuring" or "fundamental reorganization of conceptual framework" as representational change (p. 200). It is perhaps unfortunate that we use the term *structure* as referring to something distinct from representation. But by structure, we refer to the properties of a representation.

Perhaps two examples will clarify the intended meaning here. A dramatic illustration of representational change would be the change in children's reliance on a predominantly imaginal mode of representation to a symbolic or linguistic mode (Bruner, Olver, & Greenfield, 1966; Piaget, 1971). It has been assumed that children are incapable of encoding or representing certain concepts until the nature of their representation changes to conform with the concepts (see further discussions by Carey, in press; Keil, 1981; Mandler, in press).

An example of structural (but not representational) change is the commonly discussed change concerning the modification of conceptual representation from a predominantly linear mode to a hierarchical treelike structure. The treelike nature of conceptual representation is usually revealed by measuring agreement among subjects concerning the degree of relatedness among concepts. Relatedness or clustering is indexed by the proximity of the concepts during sorting and recall. Adults typically recall and sort concepts in clusters corresponding to taxonomic groupings, and this can be captured in a hierarchical tree structure (Friendly, 1977; Johnson, 1967). Furthermore, skilled adults' structure will be more treelike than less-skilled adults' (McKeithen, Reitman, Rueter, & Hirtle, 1981). In the developmental work, one could also say that the structure changes with increasing age, becoming more hierarchical, suggesting greater agreement among subjects, greater taxonomic clustering, and better fit of the data to a tree structure (Corsale & Ornstein, 1980). But the nature of the representation remains the same, consisting of concept nodes and links.

Perhaps a better term to use would be *organizational* rather than *structural change*. But the implications of organizational change seem more limited, referring predominantly to reorganizing existing knowledge, without an explicit reference to the possibility of adding or deleting knowledge as well. Organization sometimes also refers predominantly to the quantity or amount rather than the more qualitative aspects of reorganization. Hence, it is preferable to preserve the term *structural change* to refer to the kind of organizational changes to be discussed in this article. (For further discussion of the relation between structural and representational change, see Chi & Rees, in press).

The present research is concerned with elucidating what constitutes better structure rather than more knowledge or representational change. This will be done by assessing and comparing the knowledge structures of two subsets of a domain of knowledge that a child possesses: a subset he or she knows more about and a subset he or she knows less about. The assumption is that the same kind of representation underlies the two subsets of a knowledge domain. The goal, then, is to identify the attributes of a knowledge structure that make one subset of knowledge more structured than another subset. Subsequent memory performance differences on the two subsets will be used as an index of the validity of the assessed structures.

Although this is not a developmental study, developmental extrapolations are intended. Age groups are not compared, because age differences (as well as skill differences) tend to produce results that are dominated by the older age group's greater knowledge, and any structural change that may exist is often overshadowed by this greater knowledge. Age groups are also not compared for another reason, namely, that age trends are often contaminated by changes in other factors, such as strategic usage and memory capacity. By studying differences in the attributes of a knowledge structure within a single child, we will be able to assume that strategic usage and capacity limitation remain relatively invariant under different stimulus conditions. The implications of the present results for development will be discussed later.

Because strategic usage and capacity limitation are ignored, this study focuses only on the role of knowledge, narrowly defined as knowledge of concepts. Concepts are represented as a semantic mapping of nodes and their related properties in a network of nodes and links (Anderson, 1976; Collins & Loftus, 1975; Collins & Quillian, 1969; Norman & Rumelhart, 1975). Attributes of the network structure will be assessed by the number of links between nodes, the strength of linkages, and the cohesiveness of the entire collection of concept nodes in semantic memory.

Method

Subjects

To evaluate the effect of knowledge on memory performance in a child, it is necessary to select a domain in which a young child could be expert. A 4½-year-old boy who had been exposed to dinosaur information for about 1½ years was chosen. Like many children of his age, he was very interested in dinosaurs and was highly motivated to learn about them. His parents read dinosaur books to him often during this period (an average of 3 hours per week), and he had a collection of nine dinosaur books and various plastic models for use in play.

Tasks to Elicit Knowledge

Two tasks were used to elicit which dinosaurs the child knew and what he knew about each. The production task, conducted first, simply asked the child to generate the names of all the dinosaurs he knew. To maintain his interest, whenever he generated a particular name, a plastic model of the named dinosaur was handed to him. In this manner, the production task became a collectionlike game. When the child paused for a long time (about 10 seconds), the experimenter would probe with a particular dinosaur, such as "How about Stegosaur?" This production task was conducted for six sessions, spanning about 2 weeks. A total of 46 distinct names were generated (including a few names of extinct mammals), with about 25 dinosaurs generated at each session.

To gain information about what the child knew about each dinosaur, a clue game was devised in which the chooser generated a list of properties (usually 2 or 3) and the guesser identified the dinosaur to which these properties belonged. For example, the experimenter (or the child) might say, "I am thinking about a plant-eating dinosaur, and his nickname means double beam." By alternating roles between the experimenter and the child, information was obtained about the child's recognition and spontaneous generation of a subset of the dinosaurs and their properties.

Stimuli

The stimuli used for both the semantic mapping and the memory tasks (to be described) were 40 dinosaurs selected from the 46 generated during the production task. Six names were discarded for a variety of reasons. Some, for example, referred to extinct mammals (such as Wooly Rhinoceros) that are often mentioned along with dinosaurs in the dinosaur books.

The 40 dinosaurs were grossly partitioned into a better known and a lesser known list of 20 each, based on two external criteria: mother's judgment and frequency. The mother subjectively judged whether a given dinosaur could be considered better known (List A) or lesser known (List B) to the child. After the mother's judgments were made, frequency of the two lists was determined by measuring the proportion of the child's nine books that mentioned each dinosaur. List A dinosaurs were mentioned on the average in 50% of the nine books, and List B dinosaurs were mentioned in 20% of the books. Thus, the frequency of mention of the two lists was consistent with the mother's judgment of the child's knowledge of each dinosaur. The two lists of dinosaurs are shown in Table 1.

Tasks to Measure Memory Performance

Two tasks were used to measure memory performance. The recall task consisted of presenting each list of 20 dinosaur names (Lists A and B in Table 1) orally at a rate of 3 seconds per item, after which the child was asked to free recall the names just presented. Three free recall trials were presented for each type of list, separately, on consecutive days. The order of items (within each list) was randomized for each presentation.

The naming task, conducted a year after the recall task, was aimed at measuring the amount of retention. It consisted of presenting a picture of a dinosaur to the child and requiring him to name the dinosaur. Since the child could name pictures of all the dinosaurs used in this study, any loss after a year would be attributable to forgetting.

Mapping the Semantic Network

Dinosaur–dinosaur links. The sequencing of dinosaurs generated in the production task was taken as ev-

Table 1
Dinosaur Categories and Their Members

Dinosaur category	List A	List B
Armored	Ankylosaur Glyptodont Monoclonius[a] Protoceratops Stegosaur[a] Styracosaur[a] Triceratops[a]	Polacanthus[a]
Duckbills	Iguanodon Lambeosaur Pachycephalosaur Trachodon	Camptosaur Corythosaur Parasaurolophus Plateosaur[a]
Giant meat eaters	Allosaur Tyrannosaur	Ceratosaur[a] Gorgosaur
Water-dwelling reptiles	Plesiosaur	Archelon[a] Elasmosaur Icthyosaur[a] Mosasaur Tylosaur
Early meat eaters	Dimetrodon	Sphenacodon
Lightweight bird or egg eaters		Compsognathus Ornitholestes[a] Oviraptor Saltoposuchus[a] Struthiomimus
Giant plant eaters	Brachiosaur[a] Brontosaur[a] Diplodocus[a]	
Flying reptiles	Archeopteryx Rhamphorhyncus	
Ancient precursers		Diplocaulus Seymouria

[a] Indicates the targets.

idence of dinosaur–dinosaur linkages. For example, if Triceratops and Stegosaur were generated in succession, a link between the two was assumed to be present in the semantic network. No link was mapped between two dinosaurs mentioned in sequence if the sequence was interrupted by the experimenter's prompt, which usually occurred after the child paused for 10 or more seconds. Multiple links between a given pair of dinosaurs were represented in the network when the pairing was mentioned several times throughout the six sessions of protocols. Thus, the frequency of mention in the protocol was taken as a measure of the strength of linkages.

Dinosaur–property links. The dinosaur–property linkages were derived from the clue game. For simplicity, no discriminations were made between those properties that the child could recognize (i.e., generated by the experimenter) versus those that he could generate. Properties that were mentioned across several different dinosaurs were depicted as linked together in the semantic network. For example, "eats plants" was a property that was associated in the protocols with several dinosaurs, such as Brachiosaur, Triceratops, and Stegosaur. "Eats plants" was thus viewed as a common property shared by all of those dinosaurs, and in Figure 1 it is mapped as a shared diet node.

Six key types of property nodes were generated or recognized by the child in the clue game: appearance, such as "a small head"; defense mechanism, such as "it has horns"; diet, such as "eats plants"; habitat, such as "lives in the water"; locomotion, such as "walking on hind feet"; and nickname, such as "three-horned face" for Triceratops. These property nodes are labeled by the appropriate letters in the figure and attached to the dinosaurs with which they were associated. When it is ambiguous whether a property (such as spines) should be classified as an appearance or defense mechanism node, both labels are provided in the figure. A few additional properties peculiar to only one or two dinosaurs were also mentioned, and these are labeled as other nodes.

The rationale underlying the methodology of mapping is loosely based on assumptions of a spreading activation model of memory (Anderson, 1976; Collins & Loftus, 1975). Thus, dinosaurs were viewed as linked together if they were mentioned in succession, because presumably the mentioning of one dinosaur triggered the activation of a closely related dinosaur. Also, identical properties mentioned in association with several dinosaurs were linked as sharing the same property, because it is assumed that nodes in memory are nonredundant.

Groupings. Another way to discuss the structure of a semantic network is in terms of higher order units. It is assumed that concepts fall into internal units or groups. From our own knowledge of dinosaurs and the way they were categorized informally in the child's books, we imposed an organization on these mappings by classifying the total set of 40 dinosaurs into nine groups. Table 1 shows the category names and their members. Using this procedure, each list of 20 dinosaurs could be classified into seven of these nine groups, thus indicating that the two lists were partially overlapping in terms of the dinosaur groups sampled.

Selection of subsets: Targets. Two problems arise if mapping of all List A dinosaurs is compared with that of List B dinosaurs. First, the child undoubtedly knew more about the List A dinosaurs, as a whole, than the List B dinosaurs, because List A dinosaurs, on the average, were mentioned more frequently in the nine books than the List B dinosaurs. Further, more information was provided in the books about the List A dinosaurs. Assuming that a child can only learn and remember a subset of what is presented, the amount of property information known about the List B dinosaurs must necessarily be less than the amount of property information known about the List A dinosaurs. Thus, differences in the two mappings would undoubtedly be contaminated by this factor.

The second concern about analyzing and comparing the mappings of the entire sets of 20 dinosaurs is a methodological one. That is, because there was no control over which dinosaurs the child would choose to include in the clue game, many dinosaurs were not sampled. Hence, we do not have a complete assessment of the child's knowledge of properties for all 40 dinosaurs. Thus, to eliminate biases due solely to the number of

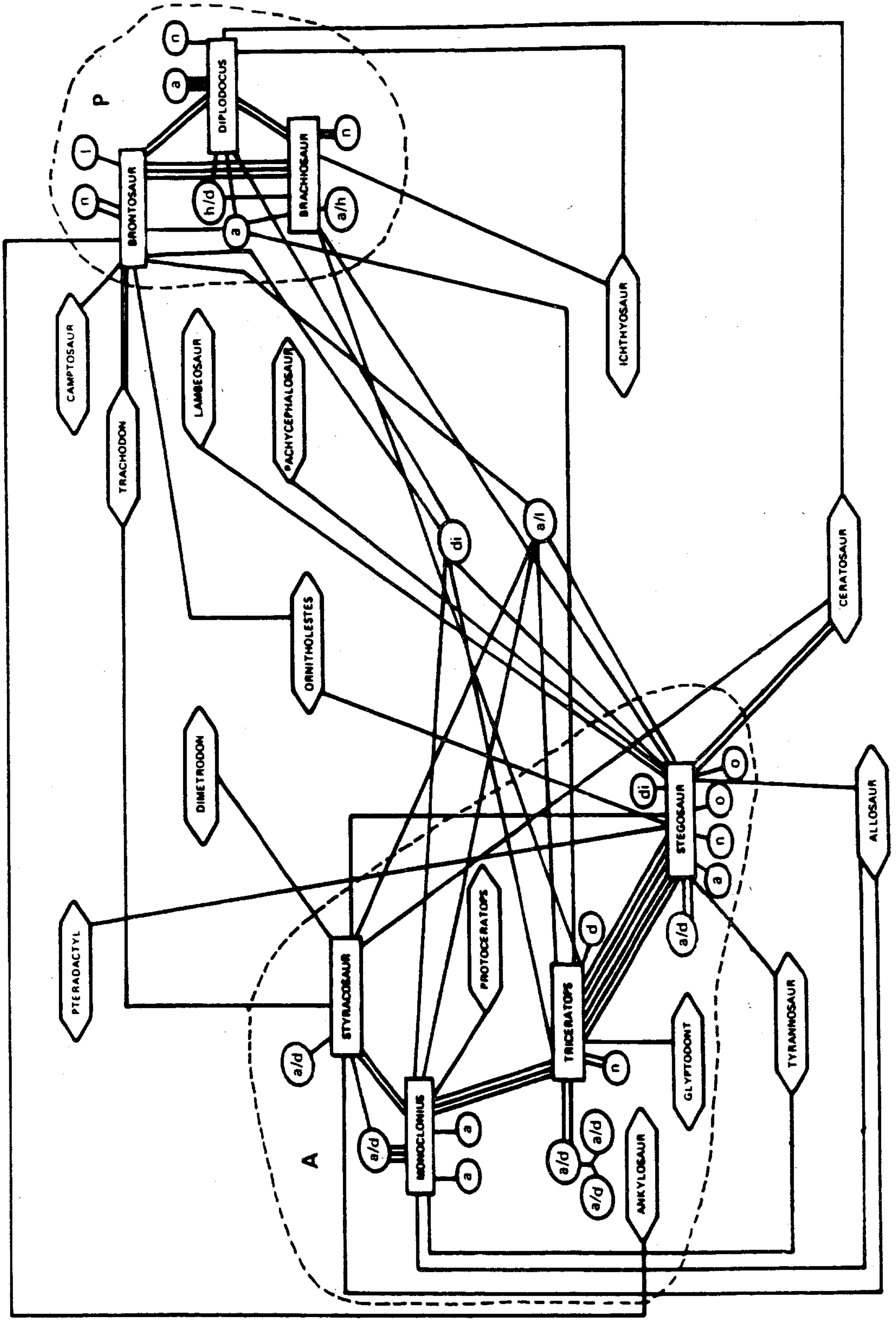

Figure 1. Network representation for the target dinosaurs from the better known list. (A = armored; P = giant plant eaters; a = appearance; d = defense mechanism; di = diet; h = habitat; l = locomotion; n = nickname; o = other.)

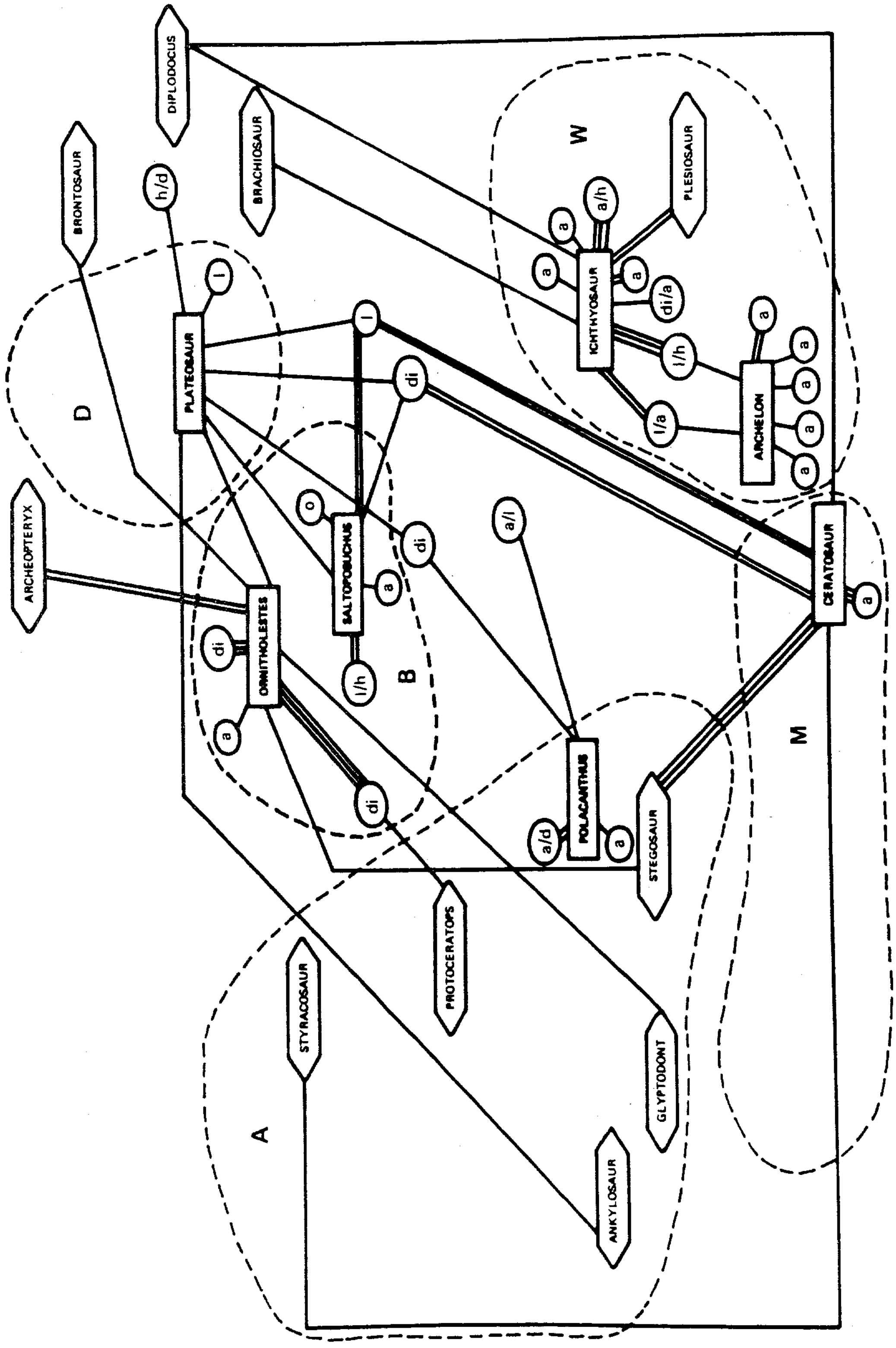

Figure 2. Network representation for the target dinosaurs from the lesser known list. (A = armored; B = bird or egg eaters; D = duckbills; M = giant meat eaters; W = water dwellers; a = appearance; d = defense mechanism; di = diet; h = habitat; l = locomotion; n = nickname; o = other.)

times particular dinosaurs were mentioned (thus producing a sampling bias and inflating the amount of information known about the List A dinosaurs), two subsets of seven dinosaurs were selected from each of the 20-item lists. These subsets of dinosaurs (henceforth referred to as the targets; see Table 1) were matched on the frequency with which they were sampled by both the experimenter and the child during the clue game. Hence, the actual mappings in Figures 1 (the better known List A) and 2 (the lesser known List B) are only for the target dinosaurs and all of their associated links (both dinosaur–dinosaur and dinosaur–property).

In the figures, target dinosaurs are enclosed in rectangles, nontarget dinosaurs (those that are mentioned in association with the targets) are enclosed in hexagons, properties are enclosed in ovals, and groupings are circumscribed by large circles. Figures 1 and 2, although mapped separately, are not intended to indicate that the two representations are distinct in memory. We conceive of one interrelated network for all 40 dinosaurs. The two parts have simply been separated for ease of analysis. In fact, we have attempted to map the network so that identical nodes on Figures 1 and 2 appear in approximately the same location. To see the interrelated network, Figures 1 and 2 can be overlaid, one on top of the other, and redundant nodes should overlap. This is merely our attempt to indicate that the two mappings represent an interrelated semantic network in memory.

To summarize, dinosaur concepts were linked when they were mentioned by the child in succession in the production protocols, and properties were linked to dinosaurs when they were identified or generated by the child in the clue game protocols. Then, the entire set of 40 dinosaurs was partitioned into nine groups. For simplicity, the network was mapped separately for the two lists. Furthermore, to reduce differences between the two mappings that might arise only from having more property information in the better known List A dinosaurs, 7 targets from each list of 20 were selected and mapped in detail in Figures 1 and 2. These subsets of 7 were matched on the frequency with which they were sampled in the clue game protocols. Because the selection criteria for the targets were controlled on the basis of the amount of information known, the resulting distribution of the targets among the groupings was not uniform (see Table 1). This variability has to be tolerated when working only with what the child knows.

Results

Comparison of the Two Mappings: Targets

Links. Since the two target sets were chosen to minimize differences in the amount of property information, it is not surprising that they do not differ in the average number of property nodes associated with each target dinosaur ($M = 5.1$, $SD = 1.70$, for Figure 1; $M = 4.7$, $SD = 1.57$, for Figure 2). What does differ between the two mappings is the average number of links associated with each target dinosaur (15.86 for Figure 1, 10.00 for Figure 2), $t(12) = 4.81, p < .01$. Because there were no differences in the number of property nodes associated with each target dinosaur, this difference in linkages arose from a higher proportion of links between dinosaurs (59% in Figure 1 versus 21% in Figure 2), $t(12) = 5.39, p < .01$. A difference between the two subsets also occurred for the strength of the linkages, as indexed by the frequency of mention in the protocols. All of the List A target dinosaurs in Figure 1 have multiple links to at least one other target dinosaur, whereas none of the List B target dinosaurs in Figure 2 does. In sum, the target dinosaurs of the better known List A mapping are more strongly interlinked than the targets in List B.

Groupings. To provide some psychological reality to the assumed groupings, the semantic mapping needs to show some measure of greater cohesion among target dinosaurs within a group and less cohesion among targets between groups. The validity of the groupings is quite strong in the List A target dinosaurs. List A targets fall into two categories: armored dinosaurs and large plant eaters. Two measures of cohesion within groups can be discerned. First, target dinosaurs showed multiple direct (dinosaur–dinosaur) links to target dinosaurs within the same group and either no direct or only single links to targets of the other group. The targets in Group A, for example, shared on the average three links with each other. Second, targets within a group shared more properties with each other than targets in different groups. That is, there were more indirect (dinosaur–property–dinosaur) links within than between groups (see Figure 1).

This pattern of differential interlinkages among targets (i.e., more links within a group than between groups) is not apparent for the lesser known List B dinosaurs. The seven List B targets fall into five groups. Since five groups are present with only seven targets, one would not expect a strong pattern of interconnections. However, even for those groups that do contain two members, no apparent pattern of strong interlinkages within groups was present. For example, there were no direct dinosaur–dinosaur links in Figure 2 between the targets within either Group B (lightweight bird or egg eaters) or Group W (water-dwelling reptiles), nor was there evidence of greater property sharing among the targets within as opposed to between groups. There seemed to be just as much sharing of properties (indirect links) among targets of different groups (such as between Group B and Group M, giant meat eaters) as there was within a group (such as Group W). This suggests that the internal cohesiveness of the List B groups was less well defined, with more uniform interconnections among dinosaurs of different groups.

Comparison of the Two Mappings: Entire Sets

Further evidence that groupings are stronger for the better known dinosaurs can be discerned by examining the overall pattern of linkages for all 40 dinosaurs. There are eight direct (dinosaur to dinosaur) linkages between members of the three main groups in List A (armored, duckbills, and giant plant eaters), to which 70% of these dinosaurs belong, whereas there are only two such direct linkages between members of the three groups in List B (lightweight bird or egg eaters, duckbills, and water-dwelling reptiles), to which 70% of those dinosaurs belong. Moreover, seven indirect linkages between the same three dinosaur groups in List A exist, because they explicitly share common properties. Only two such indirect linkages exist between dinosaurs in the three main groups of List B. Again, the greater amount of direct and indirect linkages among List A dinosaurs suggests that they tend to form more cohesive and interconnected units, whereas dinosaurs in List B tend to form a more weakly and uniformly connected whole.

In sum, the two semantic mappings of the better and lesser known target dinosaurs did not differ in the total number of target dinosaur nodes (seven in each subset) or the average number of property nodes (about five) per dinosaur node. Nor did the two sets of 20 dinosaurs differ in the total number of groupings into which each set could be classified (nine in each set). These differences were controlled to a certain degree, because the focus of this research was not on identifying trivial differences in knowing more (i.e., having more nodes or more groups in memory). In general, such differences were considered self-evident and less interesting psychologically. Instead, the interest was in how the organization of knowledge might differ for items judged more or less knowable.

The results suggest that in the semantic mappings of the target subsets, the better known mapping (compared with the lesser known) has (a) a greater total number of interdinosaur links, (b) greater strength of linkages, and (c) greater cohesion of target dinosaurs, defined in terms of stronger within-group and weaker between-groups direct and indirect links. This latter difference is also apparent when the entire sets of dinosaurs are compared. It is postulated here that these three attributes can be used to characterize the properties of a better structured knowledge base.

Recall and Retention

The child's memory performance on the two lists showed marked differences. The dinosaurs recalled from List A numbered 10, 8, and 9 (out of 20) across the three trials, compared with 6, 4, and 3 from List B, $t(4) = 5.83, p < .01$. In both cases, targets from each list were recalled proportionally to the frequency of targets in each list (35% of each list were targets). That is, of the dinosaurs recalled on each trial, 39% were targets from List A and 31% were targets from List B. The intrusion rates were also low on an absolute basis; for List A, there were on the average 1.3 intrusions across the three trials, and for List B, there were 2.0 intrusions.

If the experimenter-imposed groupings mentioned in previous sections match well with the child's own groupings, then presumably the recall order should reflect clustering according to groupings. Clustering was measured by the number of successive dinosaurs recalled from the same group, using Bousfield's (1953) ratio of repetition (RR) scoring. All intrusions were ignored, but repeated items were included in the calculation. List A recall trials had on the average an RR score of .67, whereas List B recall trials had on the average an RR score of .17. Although the greater clustering of the better known list is consistent with the notion that List A dinosaurs represent a more cohesive and better structured set of items, this particular analysis may be questionable, because the underlying assumption of equal distribution is not met. Further, as Murphy (1979) has noted, an RR score is confounded with the amount of recall.

The child's memory after a year of infrequent exposure to dinosaurs was measured by his ability to name a dinosaur when a picture of it was presented. Eleven of the 20 List A dinosaurs were identified correctly by name, whereas only 2 of the 20 List B dinosaurs were correctly named, $\chi^2(1) = 9.23$, $p < .005$. One interpretation of name identification is that it requires the association of the visual appearance or properties of a dinosaur with the name of the dinosaur. The greater retention of the better known dinosaurs is consistent with the interpretation that properties of the better known dinosaurs were attached with greater strength than the dinosaurs of the lesser known list.

In sum, the better recall, clustering, and retention performance of the child on List A dinosaurs may be interpreted to derive from two sources. First, better memory for the better known dinosaurs could arise from knowing more in the simple sense, that is, knowing more properties about each dinosaur. Although we did not quantify precisely how much more the child knew about List A dinosaurs, this assumption is fairly conservative. However, we believe that the more potent source affecting recall is not knowing more in the simple sense.

Rather, we offer the second interpretation that better recall and retention of list of items may be influenced by how well the composition of the list of items matches the structure of the knowledge base, defined here in terms of the number of direct and indirect links among dinosaur concepts, the strength of linkages, and the particular pattern of intra- and interlinkages, which delineates the cohesion of groupings. Because the mappings of the List A dinosaurs (at least the targets) are more structured than those of List B, this is correlational evidence that such structures might have induced the memory performance patterns. However, there is more concrete evidence favoring the second interpretation, namely, that targets were not recalled to a greater degree than nontargets. This suggests that knowing more property information per se about the targets did not facilitate their recall.

Discussion

It has long been known in the adult literature that knowledge facilitates recall. Chi (1976) has suggested that knowledge may also underlie developmental trends in memory. That is, adults may generally perform better than children on memory tasks because they know more than the children. In fact, recent evidence has shown that the commonly observed developmental improvements in memory performance are no longer obtained when children know more than the adults (Chi, 1978) or when children and adults are not tested on the same set of stimuli (Lindberg, 1980). That is, if adults and children are tested on stimulus material that they each know, then their memory performances are comparable, because what is considered familiar to the adults may not be familiar to children (Chi, 1981; Dempster, 1978).

In this study, we were not interested in capturing more knowledge in the sense of a larger quantity of knowledge or larger sized structures, nor were we interested in depicting knowledge differences as a change in the representation. Further, we did not specify the quality of structure in terms of quantities, such as larger group sizes or larger numbers of groups. Rather, we postulated that the entire network has the same representation for more and less knowable sets of dinosaurs. The difference between them lies in the particular configuration of nodes and links. Comparisons of the two knowledge sets were then based on a set of attributes identified from the protocol data as relevant for distinguishing the cohesiveness of the structure. Therefore, this research has developed procedures for eliciting the semantic representation of a knowledge domain as well as suggested measures for quantifying important features of knowledge organization, such as density, strength, and cohesiveness.

This study is unique in another way: It mapped the semantic network of conceptual knowledge from protocol data generated by a subject. In the majority of the existing research in which semantic networks are depicted, they are generally constructed from the researcher's assumptions or theory of structure. Then the validity of the structures is tested with specific tasks (the top-down approach). For example, Collins and Quillian (1969) constructed a hierarchical network and tested its structure with sentence verification tasks. Likewise, Gentner (1975) constructed networks for possessive verbs such as *give* and *take* and tested their order of acquisition in terms of children's comprehension. This study, in contrast, did not construct a semantic network from our analyses or intuition. Instead, a network was constructed from the child's protocols, and attributes of interest that might define differences between structures were sought (the bottom-up approach). The only aspect of the network that was top-down was the groupings.

This study was also able to focus only on the representation of concepts, ignore the role of strategic usage and memory capacity by considering the performance of a very young child, and examine only within-subject variations. By choosing a 4-year-old and examining only within-subject performance, it can be assumed with some degree of confidence that the standard adult retrieval strategies are not effectively used (Myers & Perlmutter, 1978).

Therefore, differential recall, retention, and clustering measures on two subsets of a knowledge domain can hardly be attributed to differential application of retrieval strategies. Even if retrieval strategies were available to the child, there is no logical reason why a child would apply them differentially, that is, in one subset of the knowledge domain and not another. In addition, capacity issues can be ignored when only within-subject comparisons are made. We offer the implication that developmentally, if strategic usage and capacity limitations do play a role in memory performance, their effects may appear enhanced because of the concurrent changes in the knowledge structures with increasing age.

In sum, we think such detailed analyses of the knowledge base have provided insights into the exact nature of a child's performance on memory and other cognitive tasks as well as highlighted the important attributes that may define and discriminate the structure of knowledge representation.

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