# How Knowledge Is Structured and Used by Expert and Novice Children

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This research contrasts the knowledge structures of expert and novice children in the domain of dinosaurs, as well as how this knowledge is used. Several measures were developed to assess differences in knowledge structures, such as how frequently children use connecting words in their production protocols and the frequency with which they switch topics in their discussion of a dinosaur. How children use their knowledge was assessed by measures such as the frequency with which they infer new implicit information about unknown dinosaurs and the frequency with which they make semantic comparisons, especially about unknown dinosaurs. These differences in the structure and use of knowledge provide a possible explanation of why expert children can better use and access their knowledge because it is more cohesive and integrated, than can novice children.

This research examines how expert children use their knowledge in a more efficient way than novice children as a function of how their knowledge is structured. In a previous study, Chi and Koeske (1983) found that a 4½-year-old child who is expert in a specific knowledge domain, such as dinosaurs, had a more cohesive and integrated knowledge structure for a set of dinosaurs that were very familiar to him and a less integrated and cohesive structure for a set of less familiar dinosaurs. The cohesiveness of a knowledge structure was operationally defined to be the pattern of interrelations among the dinosaur concepts, either through direct linkages (where dinosaur concepts are directly associated to each other) or indirect linkages (where dinosaurs are linked via an attribute node), when a semantic network of the nodes and links were derived from the child's

production protocols. For example, dinosaurs that belonged to the same family shared more direct and indirect links than dinosaurs belonging to different families.

This pattern of well-defined interlinkages was found only for the set of familiar (but not for the set of less familiar) dinosaurs. This suggests that, as a child acquires expertise in a domain, structures of knowledge (corresponding in this case to dinosaur family types) are built up such that they become more cohesive and integrated. In subsequent memory tasks, the child showed better recall for dinosaurs selected from the more familiar set, and the child also showed much less forgetting of the more familiar set of dinosaur names one year later in a recognition task. In a sorting task, the child consistently used the abstract dimension of diet—meat- or plant-eating—to categorize the familiar set of dinosaurs, and yet could not consistently sort the less familiar set of dinosaurs (Chi, 1985). These results were interpreted by Chi and Koeske (1983) to suggest that the degree of structure in a knowledge domain predicts the success of performance on memory and related tasks.

By using a contrastive design, we propose in this study to derive other measures to show that expert children's knowledge structure is more cohesive, which in turn may lead to a more competent use of that knowledge. We predict, generally, that expert children, on the basis of their greater existing and coherent domain knowledge, should be more able to use their knowledge in making inferences, inducing new knowledge, and reason about new information as it is related to existing knowledge. Hence, we propose that children's abilities to reason are dictated largely by the sophistication of their domain knowledge, as opposed to a possible alternative view, that reasoning and inferencing are abstract skills children acquire as they mature.

Following upon the Chi and Koeske (1983) work, we continue to use a semantic network representation as a framework within which we view the structure of dinosaur knowledge. Our assumption of the expert knowledge structure in the domain of dinosaurs is that it contains instances of dinosaurs, with a set of properties (or attributes) known about each instance. We assume that with learning, the knowledge base becomes increasingly organized around salient attributes, such as diet, locomotion, aggressiveness, or defense. That is, through learning, the child will notice the correlated features of each attribute (i.e., the presence of one feature is correlated with the presence of another). By noticing the consistent pattern of interrelations, the child's knowledge base becomes restructured in a more cohesive way, taking into account the relations that exist among different dinosaurs. (See, e.g., Chi & Koeske, Figure 1.)

Consequently, based on our previous findings as well as the assumptions of a spreading activation model of memory, we can make several general predictions. First, we ought to find the knowledge structures of the experts to be more cohesive and integrated than those of the novices. We will develop new measures of assessing cohesion to show that a more integrated structure has a stronger and

more well-defined pattern of links among its concepts. Measures that we will use as an indication of cohesion are the frequency with which experts' protocols contain connecting words (such as "because" and "if") as compared to novices' protocols. Another measure will be the frequency with which experts discuss different topics in relation to a given topic, thus indicating that related concepts and topics are all activated in a relatively integrated knowledge structure. Finally, we have coded the children's protocols into rules for determining class membership. Any differences in the kind of rules children use should characterize differences in the knowledge structures of experts and novices.

A second prediction we make is that experts ought to be able to use their knowledge structure in ways that novices cannot, in both helping them learn and assimilate new dinosaur concepts, as well as in the way they make decisions about familiar dinosaur concepts. We have developed three measures to assess how knowledge is used, such as the ability to infer new information, the ability to make semantic comparisons, and the kind of rules expert children use to help them reason about class membership in a way that novices do not.

We assume that the more sophisticated way the expert children use their knowledge reflects the existence of "groupings" or schemata of dinosaur families which were formed while they acquire information about dinosaurs. The presence of these well-formed family schemata will permit experts to draw inferences about unfamiliar exemplars, to contrast similarities and differences among dinosaurs, and to integrate new information into preexisting knowledge structure. In other words, not only will experts have better access to their knowledge, but they will access more structured knowledge.

Two groups of 7-year-old children were selected on the basis of a pretest of their knowledge of dinosaurs. Although we did not manipulate age, the motivation of our study was to address developmental issues: that is, to what extent are the complexity and frequency of children's reasoning and inferencing functions of expertise? If differences in performance are found between the expert and novice children, then one could conclude that domain knowledge can influence how children reason and make inferences, and thus be a potential source of developmental differences.

## METHOD

### Subjects

Fourteen male children, age 7 years, served as subjects for this study. A pretest was administered to determine subjects' degree of expertise with respect to dinosaur knowledge. The pretest included two tasks. One task consisted of showing pictures of dinosaurs and asking the child to name them; the other task required the child to answer 18 questions about instances of dinosaurs (e.g., "The name Brontosaurus means _____lizard."). On the basis of pretest scores, 5 subjects were assigned to the "expert" group and 5 to the "novice" group.

### Table 1. Dinosaur Stimuli

| | |
|---|---|
| Acantopholis | Tyrannosaurus Rex |
| Polacanthus | Allosaurus |
| Kentrosaur | Megalosaur |
| Ankylosaur | Brachiosaur |
| Scelidosaur | Brontosaur |
| Stegosaur | Diplodocus |
| Protoceratops | Corythosaur |
| Styracosaur | Parasaurolophus |
| Triceratops | Brachylophosaur |
| Monoclonius | Anatosaur |

Experts were those children who scored at least 50% correct on both tasks, whereas novices were those with a score of less than 25% correct. Four children were dropped from the study because they scored in between the critical scores.

## Material
The stimuli were 20 dinosaur pictures taken from children's books, each mounted on an individual piece of cardboard. Table 1 contains a list of the names of the 20 dinosaurs used.

## Procedure
Two tasks were administered: a production task and a sorting task. In the production task, each stimulus from the list was presented to the child, one at a time, in random order. During the presentation, the child was asked to identify the stimulus by name and generate information about it. Instructions were given to the child as follows: "Now I am going to show you pictures of dinosaurs and you are going to tell me their names and everything that you know about them."

For the sorting task, the experimenter displayed all the pictures of dinosaurs randomly on a table in front of the child. The child was instructed to put the dinosaurs "that go together" in the same group. There were no restrictions in either the criteria or the number of groups sorted. After the sorting, the child was also asked to explain the groupings.

Each child performed both tasks, in two successive sessions approximately a week apart. The sorting task was administered first and the production task, second. This order was chosen in order to avoid influencing the basis of sorting after children had described and thought about each dinosaur. Children were individually interviewed in a quiet room in their own homes. Each tape-recorded interview lasted about 30 min.

## RESULTS

Because the analysis of the production task provides more information about the underlying knowledge structure, and thus provides the basis for making predictions about the sorting performance, this analysis is presented first.

## Production Task
Children's production protocols were transcribed verbatim, and then divided into propositions. We define a proposition to be a unit of information about a feature of a dinosaur. Each proposition was coded five times, with respect to the: (a) type of information, (b) syntactive connectives used between propositions, (c) thematic content, (d) semantic comparisons used, and (e) judgment of class membership. Analyses (b) and (c) give us information about how the knowledge is structured, and analyses (a), (d), and (e) tell us how the knowledge is used. Two independent judges coded all the protocols, reaching between 92.1%–98% agreement on each analysis. Disagreements were resolved through discussion.

*Type of Information.* For the first type of analysis, the production protocols were coded into two types of propositions: *explicit* or *implicit*. Explicit propositions are based completely on observable cues from the picture. The following kinds of propositions would be classified as explicit: (a) descriptions of physical characteristics of the dinosaur (e.g., "it has three horns," "it has spikes all down the back"); (b) descriptions of temporary characteristics of the dinosaur, related mostly to ongoing actions (e.g., "the mouth is open," "he is drinking water") and (c) descriptions of the environment surrounding the dinosaur in the picture (e.g., "there is water around," "there are palm trees").

Explicit propositions also included *interpretations* of explicit cues of the picture, drawn on the basis of general world knowledge (e.g., "see, he's attacking something," "the shadow, that's what scared the mouse away") where both are an interpretation based on the picture of the dinosaur; or "looks like he lives in the desert," where the habitat of the dinosaur is inferred directly from the environment depicted in the picture. Propositions containing explicit interpretations are almost always prefaced by a direct reference to an aspect of the picture, such as "the shadow," "see," and "looks like" from the above quotes.

Implicit propositions included any kind of statement about features of dinosaurs that are neither directly perceivable nor interpretable from the picture. The following kinds of propositions were coded as implicit: (a) descriptions of physical characteristics that could not be inferred from the picture, but where specific knowledge has to be used. For example, in talking about *size*, the child said, "He is the second biggest dinosaur" and "He was about twelve feet long." In the first case, the information on the dinosaur size is expressed through a comparison with the rest of the dinosaurs, whereas in the second case, a precise measure of a dimension is given. In both cases the information must have been previously learned by the child. Another example is "Their teeth are kind of like people teeth . . . shaped like that," (when the teeth are not actually visible in the picture); and (b) superordinate information drawn from domain-specific knowledge about aspects of dinosaurs other than the physical attributes such as diet— "He is a meat eater"—or social activities—"They travel in small groups."

The results of this analysis show that experts and novices produced about the same total number of *explicit* propositions (314 by experts and 330 by novices).
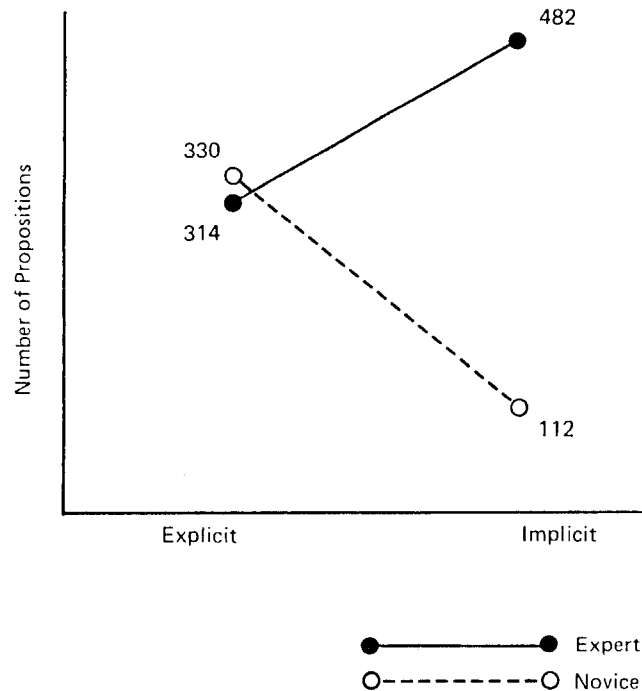
FIG. 1. **Total Number of Explicit and Implicit Propositions Produced by Experts and Novices**

This is not surprising because explicit cues were available to both groups and we would assume that physical features are available and used by both expert and novices (Figure 1). In contrast, experts produced a significantly greater number of *implicit propositions* than novices (482 and 112, respectively, $F_{1,8} = 7.072 \, p < .05$). This result is not surprising either, given that experts, upon seeing a picture of a dinosaur they know, should be able to activate its representation which then produces implicit information about it from their knowledge base. Novices, on the other hand, produced fewer statements of an implicit nature since their representations of these dinosaurs should be sparse.

A more interesting question is to know whether the implicit propositions produced by the experts is retrieved or generated from the existing representation. To determine that, the children's protocols on the 20 exemplars were divided between those that the children knew versus those that they did not know (as determined by the protocols of the production task). A dinosaur is considered *known* to the child if the child could identify it by name or by the family to which it belongs. By this criterion, experts knew an average of 15.6 out of the 20 dinosaurs and novices, an average of 3.6.

**Table 2.** **Mean Number of Explicit and Implicit Propositions Produced by Experts and Novices for Known and Unknown Dinosaurs**

|  | Known | | Unknown | |
|---|---|---|---|---|
|  | Explicit | Implicit | Explicit | Implicit |
| Expert | 2.81 | 5.22 | 3.04 | 3.57 |
| Novice | 2.19 | 1.61 | 3.22 | 1.05 |

Table 2 shows the same trend when the dinosaurs are divided into known and unknown sets. That is, compared to the novices, the experts produced a greater number of implicit information even for the unknown dinosaurs (3.57 proposition per dinosaur vs. 1.05), suggesting that this information must not be retrieved from prestored knowledge. Rather, the expert children appear to be able to use their existing schemata of dinosaur types to generate information about novel dinosaurs. However, experts and novices both generated about the same number of explicit propositions for known and unknown dinosaurs.

*Syntactic Connectives.* The second analysis of the production task is concerned with the interconnections or links between propositions in the protocols. Syntactic connectives are those that are usually taken into consideration in analyzing discourse and writing coherence. They consist of the use of word repetition, or connective words such as "because" (causal), "if" (conditional), "then" (temporal), and "or" (disjunctive). We did not consider the conjunction "and" to be a connective word because it is often difficult to discriminate whether it was used as a true connection between the propositions or whether it was used to maintain the flow in the utterances. Table 3 gives sample quotes of all five types of syntactic connectives.

Sixty-nine percent of the experts' propositions are connected syntactically, whereas 49% of the novices' productions are. One interpretation of this result is that the novices' productions tend to be a listing of features that are triggered visually by the picture. So, for example, they tend to say things like:

"He has sharp teeth. He has three fingers. He has sharp fingers, sharp toes, a big tail."

For the experts however, once some knowledge is triggered by the visual features, additional related knowledge should then be activated, assuming that knowledge is stored in a spreading activation network. Such activated knowledge, we propose, would be generated with a greater degree of continuity, thus resulting in the use of syntactic connectives in the verbal protocols. The following quote illustrates an example of experts' protocol that tends to be linked by connective words (italicized):

## Table 3.    Sample Quotes of Each Type of Link

### Syntactic Connectives

**Word repetition**
"They eat water plants; *they* live in the water most of the time"
**Causal connective**
"Probably nothing would attack them *cause* they're called the King of the Dinosaurs, *so* I imagine nothing could attack them"
**Conditional connective**
"And *if* they saw a bigger animal, they would run away from it"
**Temporal connective**
"Something could have snuck up on him and *then* try to kill it or something and *then* it ran away and the Tyrannosaurus Rex is going after it, boy it is mad"
**Disjunctive connective**
"But really if they saw a giant meateater, they would duck their head under their big back so it couldn't take a bite out of them, *or* else they'd get the big prickles in them"

"And he had webbed feet, *so* that he could swim, and his nose was and his nose was shaped like a duck's bill, *which* gave him his name."

*Topics.*    Another way to show that the experts' knowledge is more integrated is to see the extent to which they change topics in their discussion of each dinosaur. The frequency with which they change topics would indicate that many topics are related, and therefore activated, and thus would encourage the experts to discuss them.

To carry out this analysis, all the propositions were first coded in terms of six topics expressed: Physical Description (appearance, size, posture, facial expression); Defense (defense mechanism, protective body covering, trait, enemy, & prey); Biological Information (diet, specific food, reproduction, degree of intelligence or instinct); Family (nickname, family relation, evolution); Social Activity (rearing, group activity), and Habitat (locomotion, environment). The one topic that both experts and novices discussed with equivalent (proportional) frequency was *defense*. Therefore, we coded the absolute frequency with which the discussion of defense led to the discussion of another theme, and this transition frequency is depicted in Figure 2 for experts and novices. Proportionately (the number of transition over the number of defense propositions stated), the experts changed topics of discussion with much greater frequency (0.88) than novices (0.29), and the difference is significant ($F = 10.79$, $p < .01$).

The interpretation of this result is that for the experts, not only does the activation of one topic spread to activate other topics proportionally more often than for novices, but the activation also spreads to many more different topics for the experts than for the novices. Novices seem to discuss the defense mechanism mostly in relation to the physical appearance. For example, 61% of the novices'
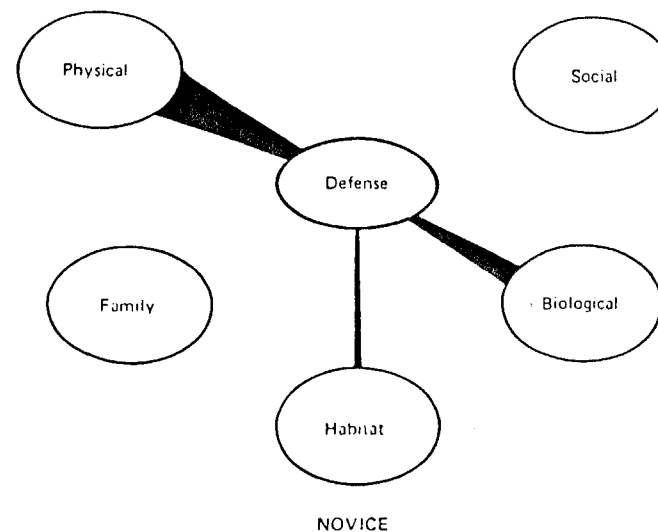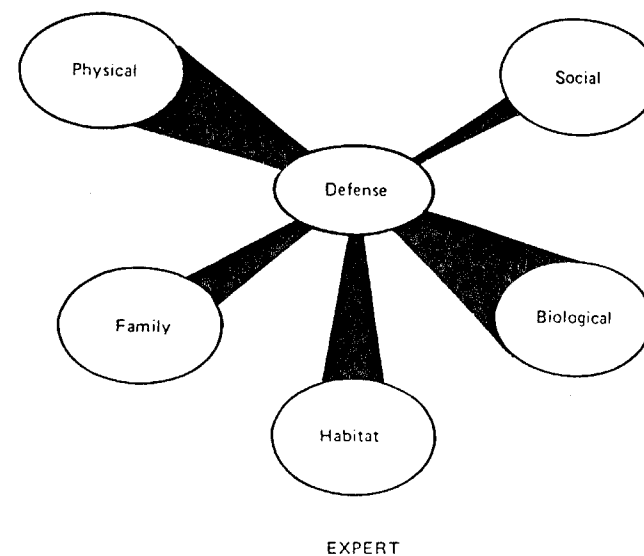


EXPERT



NOVICE

**FIG. 2.    The Frequency of Transition Among Different Topics in the Discussion of Defense by Experts and Novices**

**Table 4.   Semantic Comparisons**

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**Dinosaur-dinosaur comparison**
   "They are pretty much like Diplodocus"
**Dinosaur-attribute-dinosaur comparison**
   "And it goes in the water, but doesn't go in like Brontosaurus"
**Absolute comparison**
   "He was the longest dinosaur ever"

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transition goes to the discussion of physical appearance, whereas only 39% of the experts' transitions concerns the physical appearance topic.

*Semantic Comparisons.*   In this and subsequent analyses, we are concerned with how effectively the expert children use their knowledge as compared to the novices. One way to look at this is to examine the extent to which expert and novice children stated propositions that compare and contrast two dinosaurs, either directly (dinosaur-dinosaur comparison), or via their shared attribute (dinosaur-attribute-dinosaur comparison). Another type of comparison is absolute comparison, expressed by the use of the superlative form in comparing one dinosaur with the rest along a single dimension, such as "He was the longest dinosaur ever." Table 4 gives sample quotes of each type of semantic comparison.

The analysis of the comparison propositions suggests that the experts are able to use their knowledge of dinosaurs in an analogical way; that is, to compare them, either directly (in which case we cannot tell how many features are used for the comparison) or via a specific feature. Experts stated a total of 70 comparisons (or 8% of their total number of propositions). Among these, 18 were direct comparisons, 38 referred to a shared attribute of two dinosaurs, and 14 were absolute comparisons. Novices generated a total of 13 comparisons (3% of their total propositions), 4 being of the dinosaur-attribute-dinosaur type and 9 absolute comparisons (see Table 5). Due to the small sample size, the difference between the proportions of comparisons generated by experts and novices (8% vs. 3%) is not significant, although the absolute difference approaches significance ($F = 13.1805, p < = .0067$).

**Table 5.   Total Number of Comparisons of Each Type Made by Experts and Novices**

|  | Dinosaur-Dinosaur | Dinosaur-Property Dinosaur | Absolute | Total | Property |
|---|---|---|---|---|---|
| Expert | 18 | 38 | 14 | 70 | 8% |
| Novice | 0 | 4 | 9 | 13 | 3% |

*Judgment of Diet Class Membership.*   Another way to examine how children use their knowledge is to consider what kind of rules they use to decide what is the diet of a particular dinosaur. We focused on the diet attribute mainly because both the expert and the novice children mentioned it frequently. Thus, even the novices considered the diet to be an important dimension. We assume that this is derived from general world knowledge, because children of this age are often aware of the importance of diet for animals. Although novices knew that this dimension was important, it is not surprising that their judgment of a dinosaur's diet is often incorrect, whereas an expert's judgment is almost always correct. Our interest, however, centers on the decision rules children use to make their judgment, rather than whether their knowledge was accurate or not.

The term "rule" is used here to represent both cases in which the child retrieves specific rule that associates a causal feature of the dinosaur and its diet, such as

"That can tell me its a meat eater alright . . . cause it has all these front things around it . . . and that would keep it safe";

as well as when the child is making a general rule via comparison reasoning such as "They eat plants, kind of like Stegosaurus." We assume that experts will have direct access to specific rules from their knowledge base, that is, they can retrieve prestored rules that associate consistent feature or patterns of features with a specific diet. Even in cases where a dinosaur is unknown, experts still may be able to use the same prestored rule to determine the diet, since a subset of the features of an unknown dinosaur could match the features associated with their stored rule. Hence, they will be able to use their existing rules to reason analogically, and infer the diet information from the feature or set of features. Such a result would provide additional evidence for the interaction of knowledge and strategy use.

In contrast, the novices may not know about specific association between features that are related to diet, so they may have to build rules on-line. We wanted to see in what ways are the characteristics of their reasoning from incomplete knowledge different from the experts'.

In general, the results show that both experts and novices supported their decisions on the basis of obvious physical features depicted in the picture. Some children of both groups decided occasionally on the basis of actual eating behavior exhibited in the picture, such as a dinosaur eating plants. Hence, both the expert and novice children used clearly depicted physical cues.

What differed between the two groups is that the experts used basically four features to determine the diet, whereas the novices were not so consistent. Four of the 5 experts, for example, invoked the "long" and "sharp teeth" features to explain how they can tell a dinosaur is a meat-eater (e.g., "Obviously a meat-eater, cause he had such sharp teeth here"). All 4 children also used the absence of these features to decide that the dinosaurs belonged to the alternative class

(e.g., "Plant-eater, cause it has little teeth that aren't sharp"). Two of them stated something like that even in cases where the teeth were not visible from the picture. One of these 4 experts used a third feature, locomotion, in conjunction with another feature to determine the diet. For example, knowing that a two-legged dinosaur could be either a meat-eater or plant-eater, (depending on whether it also has a duck's bill), the child judged a Megalosaur to be a meat-eater because it did not have a duck's bill:

"He is a meat-eater and he is a two-legged animal . . .
and he didn't have a duck's bill so he couldn't be a
Igandonon or a Lambeosaur or something like that."

Moreover, the same child judged an unknown four-legged dinosaur as a plant-eater, using the same criterion of locomotion: "They probably eat plants . . . cause most meat-eaters walk on twos."

The fifth expert (the only one who did not use the criterion of the type of teeth) used a conjunction of two features as the criteria:

"Probably plant-eaters, they live on land;
those small dinosaurs that live on land are
plant-eaters; big ones are meat-eaters."

Finally, this same expert used reasoning by analogy to another exemplar of the same family to determine the diet of a dinosaur:

"He was the first King of the dinosaurs,
but until he died. Then Tyrannasaur Rex came
along. It is a meat-eater. Tyrannasaur Rex
is a meat-eater so he is a meat-eater."

Let us summarize the experts' use of decision rules before contrasting it with the way novices made decisions.

1. Experts were quite consistent among themselves in the use of one or more features to determine the diet of a dinosaur.
2. All of them were able to contrast the same feature to identify the complementary class. That is, they were able to use the absence of an attribute as an indication of the alternative class. (This suggests that their initial rule must have been coded as a biconditional in order to infer validly the *modus tollens*. For example, if "sharp teeth" is a necessary and sufficient condition to define a meat-eater, then "not having sharp teeth" would imply that it is a plant-eater.) In fact, they were able to use the same criterion whether or not it was present in the picture.
3. They were able to use general reasoning rules such as induction by generalization or by analogy.

Novices, on the other hand, are less consistent among themselves on the set of criteria to be used for judging class membership. They used a greater variety of criteria than the experts to identify the diet (9 versus 4, respectively). This greater variability in the criteria of categorization is typical of young children's class judgment (Chi, 1985), as well as consistent with adult novice's performance in classifying physics problems (Chi, Feltovich, & Glaser, 1981).

Another characteristic of 4 out of the 5 novices is that they could reason only in terms of the presence of a feature. Thus, a dinosaur is a plant-eater if a particular feature is present and a meat-eater if a different feature is present. Hence, one dinosaur could be a plant-eater because "it is hard" and another could be a meat-eater because "it has those sharp things around it." This would not pose any problem in correctly classifying dinosaurs if the features were treated as sufficient and necessary condition (i.e., its presence tells that it belongs to the class A, its absence tells that it does not). However, novices generally do not contrast the same feature in an inclusive-exclusive way. Only one novice was able to use a single feature to determine class membership (i.e., "plant-eaters because they have long necks"; "meat-eaters because they don't have long necks").

Another characteristic of the novices' decision process is that they are not concerned by the inconsistency of their decisions in response to contradictory features. For example, when a dinosaur is shown eating plants in a picture, they say that it is a plant-eater, even though the critical feature which they previously and subsequently stated as a defining feature of the plant-eater class was not present. On the other hand, after consistently stating that a dinosaur which is shown in the picture eating plants is a plant-eater, they will then ignore this attribute and decide that one of these dinosaurs is a meat-eater if a meat-eating feature is also present. This kind of inconsistent rule-use in situations with conflicting features occurred even for the single novice who appeared to use a criterion contrastively, much like the experts. Moreover, one novice even used the same feature (i.e., having horns) to assign dinosaurs to both classes, thus obviously contradicting himself. Again, in the case of this novice, it appears that the sufficient condition is missing. One interpretation of such a characteristic is that novices, like Piaget's description of the younger child, often respond to the perceptual or superficial features of a stimulus. A second possible interpretation is that novice children construct decision rules on-line, and therefore they tend to be inconsistent from one case to another. A third interpretation is that the rules that they may have prestored are incomplete (such as the sufficient condition is missing), or else they have not made the proper discrimination in their rules between characteristic and defining features.

To summarize, in contrast to the experts, novices were (1) inconsistent among themselves in the set of features that determined the diet class membership, (2) did not use a criterion exhaustively, (3) were not influenced by contradictory

features, and (4) did not exhibit any ability to use analogical reasoning or generalization. We do not want to claim from this finding that the expert children have (but the novices lack) logical abilities. Instead, we suggest that the type of reasoning used clearly interacted with expertise in the knowledge domain, supporting some of our earlier claims (Chi, 1985). Some of this is reflected in the experts' retrieval of specific prestored rules. However, experts do appear to be more able to use general rules such as reasoning by analogy. The exact nature of the interaction between reasoning and content knowledge is still unclear at the moment.

## Sorting Task

Because experts and novices appeared to differ in their knowledge structures in terms of their richness and cohesiveness, we wondered whether or not this would affect the way they sort dinosaurs. Based on previous work (Chi, 1985; Chi et al., 1981), our prediction was that experts would be more likely to base their sorting upon superordinate (more abstract) features, whereas novices would be more likely to draw a basic level sorting on the basis of explicit physical features, and the number of groups sorted will be dependent on the chosen features. However, since the abstract features are correlated with the explicit cues for natural categories (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976), it will not be possible to determine the bases of their sorts by examining which dinosaurs are grouped together. That is, dinosaurs that belong to the same family (thus sharing similar abstract features such as type of habitat, food habits, and aggressive natures) do tend to look alike. That's because in real-world categories, features co-occur and are correlated. Therefore, we will examine only the justification given by the children to their sorting.

*Analyses of the explanations.* Experts and novices both sorted the dinosaurs into an average of 4 groups, although the experts had a narrower range (2 to 5 groups) than the novices (2 to 9 groups). In order to understand the nature of their sorts, we contrasted experts' and novices' verbal justifications in terms of the type of features stated. We found that novices stated explicit physical features proportionately more often than experts (83.20% and 42.60% for novices and experts, respectively, $F_{1,8} = 7.176, p < .05$). Moreover, experts used a greater variety of topics, 2.10 versus 1.28 ($F_{1,8} = 4.819, p < .059$), and mentioned superordinate nonexplicit features (such as diet, defense, habitat) more often than novices ($F_{1,8} = 21.605, p < .01$). They also were more correct than novices in using the attribute of diet ($F_{1,8} = 8.259, p < .05$), although the 2 groups were not significantly different in the frequency of mentioning diet.

Generally speaking, these results show that although experts had the physical appearance topic available, they sorted on the basis of a combination of attributes, which often resulted in a family distinction. This is consistent with the characterization made earlier about experts and novices' knowledge structures.

In fact, our interpretation of the sorting task is that the picture was activating experts' representation from which they retrieved superordinate topic information (like information about diet, defense, habitat, etc.), whereas novices' lack of preexisting knowledge hindered their ability to rely on any attributes other than the physical ones.

Another characteristic of the expert children's sorting was exhaustiveness. Experts always made an exhaustive sorting, whereas 2 novices left a residual group. Novice groups also tended to be inconsistent. For example, 1 novice sorted the dinosaurs into 3 groups, the third (residual) group was defined on the basis of features shared by some members of that group, but also by members of the other 2 groups, although at the same time there was no one feature shared by all members of the third group. Thus, these 2 novices were not able to find an exclusive criterion to make the classification exhaustive. In our interpretation, this was due to the fact that their sorting was directly driven by isolated explicit cues, without being able to organize them to find the distinctive ones.

Experts consistently used the family and diet attributes for the basis of their sorts. Two experts sorted on the basis of the 2 classes of diet, and then when prompted to continue sorting of these 2 major classes, they chose to sort each of the 2 groups on the basis of family and physical appearance. This is consistent with some of our earlier findings from other expert children's dinosaur sorts (Chi, 1985).

## CONCLUSION

There are three major conclusions to draw from this exploratory research. The first point to note is that, consistent with our previous expert-novice research with both children in the domain of dinosaurs and adults in the domain of physics problem solving (Chi, 1985; Chi et al., 1981), one dominant finding is that novice children tend to focus on the explicit "surface-type" features of concepts, whereas experts focus on the implicit or "deep-level" concepts. This can be seen in our data in at least two ways. First of all, expert children produced a greater amount of implicit information about dinosaurs than novice children, whereas they both produced the same amount of explicit information. Secondly, when children were asked to sort dinosaurs, novices tended to state explicit physical features as the basis of their sorts, whereas experts tended to state implicit features.

The second conclusion we would like to offer is that the experts' knowledge of dinosaurs is more structured. By more structured we mean that the knowledge is more integrated and cohesive. There are several pieces of evidence that can be used to characterize this cohesiveness. For example, the experts' production protocols are much more connected syntactically, either by word repetition or connectives such as "because" and "if". That is, novices' generation of information tended to mimic the production of a list of features, whereas experts'

generation of information took the form of a more coherent discourse, suggesting that there are greater associations among concepts within the experts' (than the novices') knowledge structure.

Another piece of evidence is that for the experts, the generation of one piece of information activates the generation of other knowledge associated with it. This is particularly true for implicit information. The analysis of the frequency of transition between the mentioning of defense topic and other topics exemplifies this point. This suggests that different topics or features are not stored in isolation, but rather form an associative network. One interpretation for this associated connectedness is that in order for the child to learn about dinosaurs in a sensible way, he or she must realize the causal connection between one feature (e.g., "it has horns or an armor") and another feature (e.g., "it has to protect from other dinosaurs that would try to eat it; very likely it is a plant-eater"). With experience in the domain, the child could use this knowledge of causality pattern to make predictions about features of new instances of dinosaurs.

A third piece of evidence to suggest that experts' knowledge structure is more cohesive is the finding that experts appear to use one small set of features to contrast two classes. That is, the presence or absence of a small set of features (such as "long" and "sharp teeth") determined whether a dinosaur belongs to the meat-eating or plant-eating class. Novices, on the other hand, could only reason predominantly with the presence of a feature. That is, if it has "sharp teeth," it might be a meat-eater, but if it has "long necks," then it might be a plant-eater. The use of one set of features to discriminate two classes can be viewed as more integrated because the two classes would then share this one set of attributes.

The third major conclusion we would like to offer from this research is that the consequence of having a more structured knowledge (in the expert children) is that it allows the expert children to use this knowledge in a more sophisticated and accessible way (Chi, in press). We again can point to three pieces of evidence to suggest this. First of all, the expert children can use their structured knowledge to infer a great deal more implicit information about unknown dinosaurs than the novice children. Thus, even in cases in which an expert child does not know a particular exemplar, he is able to consider it a member of a certain family group or schema on the basis of some explicit features and infer additional knowledge about it. Novices were significantly poorer at drawing implicit information about unknown dinosaurs, suggesting that they lack the appropriate schemata of dinosaur types with which to embed an unknown dinosaur. This emphasizes Chi and Koeske's (1983) point that knowing a great deal about a few exemplars neither constitutes nor produces good structure; unless the few that they do know all belong to the same family or schema.

The second piece of evidence in support of our conclusion that expert children can use their knowledge in a more sophisticated way is shown by the frequency with which they make semantic comparisons. That is, they reason analogically in

terms of comparing the similarity of dinosaurs either directly or via a shared feature. Novices generated this kind of semantic comparison infrequently. Each expert for example, drew an average of 14.6 domain-related comparisons, either pointing at similarities or at differences between dinosaurs, whereas each novice on the average, drew only 2 such comparisons.

A third piece of evidence is that, in deciding upon the diet of a specific dinosaur, expert children could reason with both the presence or absence of a feature to determine class membership. Novices, on the other hand, tended to be able to infer only on the basis of the presence of certain features to indicate class membership. Furthermore, novices cannot reverse their decision when confronted with contradictory features. In sum, the expert children's greater ability to (1) infer implicit information about unknown dinosaurs, (2) reason analogically via semantic comparisons, and (3) use one set of features to contrast two classes, all suggests that their abilities probably derive from having a more cohesive and integrated knowledge structure.

In conclusion, this research begins to provide some understanding about how more structured and cohesive knowledge in expert children can facilitate their use and access of their knowledge in a way that appears more developmentally mature than novice children of the same age. This research also contributes yet another piece of evidence showing the interaction between children's available knowledge and their ability to use that knowledge.

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