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8 Children's Lack of Access and Knowledge Reorganization: An Example from the Concept of Animism

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Currently, a popular interpretation for young children's limited performance is the concept of lack of access. More specifically, this concept assumes that the knowledge that is needed to perform a specific task is available to the child, except that somehow, the child cannot access this knowledge or use it. This paper attempts to understand this idea in terms of knowledge organization and how knowledge might be reorganized to facilitate access. The exact nature and definition of lack of access are postulated and preliminary exploratory data to demonstrate what lack of access could mean for young children is presented in the domain of animism.

EMPIRICAL DEFINITION

"Lack of access" is an interpretation imposed upon an empirical phenomenon that is often observed in young children's cognitive performance. A few examples are offered to illustrate the phenomenon. Young children are often not capable of pairing or categorizing items on the basis of taxonomic relations. For example, if given a choice of whether to pair *scissors* with *knife* together or *scissors* and *paper* together, younger children would prefer to pair the scissors and paper because scissors cut paper, whereas older children may prefer to pair scissors and knife because they are both tools that can cut things. Thus, younger children rely on thematic relations, rather than the underlying taxonomic organization. The reason that this phenomenon is labeled *lack of access* to the relevant knowledge is because the necessary knowledge appears to be available when probed. For example, in a match-to-sample task, if children are shown a cow and asked "to find another one that is the same kind of thing," they will pick another animal (such as a pig) rather than a thematically related picture, such as milk. Markman and Hutchinson (1984) claim that the provision of a verbal label (cow) constrains the search of "another one" to another animal, thus focusing children's attention to categorical relations. This suggests that children are capable of accessing taxonomic relations when they are properly constrained.

Similarly, given a string of items to recall, younger children's recall will typically not show a clustering of items on the basis of taxonomic relationship. One byproduct of nonclustering is lower recall. Again, a current interpretation for this kind of recall pattern is not that children lack the taxonomic relations among the items, but rather, that somehow *they prefer not to use them* since their recall could be improved if their attention was drawn to the taxonomic relations (Smiley & Brown, 1979).

The thesis of my paper proposes that lack of access has to do with the way the knowledge is represented. That is, knowledge is not accessible when it is not properly represented. What constraining does (such as by providing a noun for a category member, as in the Markman & Hutchinson study) is to restrict the search for the child. Constraining the search for the child still does not explain why under normal situations, children do not access that knowledge readily. Thus, we would like to explore the idea that development is a change in the overall structure of knowledge, which permits children to access their knowledge without having their search restricted by the experimental task. Although this framework does not emphasize the existence of a limited accessing mechanism, the same set of questions would be posed as critical to our eventual understanding of cognitive development as those proposed by Gelman and Baillargeon (1983), namely: (1) what is it about the early representation of a given set of experiences that prevents them from being accessed; (2) how must this representation be changed so that it can be accessed (that is, what are the processes that can produce such changes); and finally, (3) what external experiences can foster such changes. In this paper, I focus primarily on answers to the first question, speculate on the answers to the second question, and refer to literature that addresses the third.

ENCAPSULATED MICROSTRUCTURES

It is all well-and-good to postulate that the way knowledge is represented is the culprit for lack of access. Such hypothetical statements cannot be taken seriously unless one can support it by empirical evidence. One way to understand what it means when knowledge is represented in such a way as to be inaccessible is the idea that knowledge is often not accessed because the conditions under which it needs to be retrieved does not match the conditions under which it was stored. This situation tends to produce the phenomenon that children's knowledge is

contextually bound, that is, it can only be accessed in one context and not another. What this means, essentially, is that it was stored under one set of contexts and thus it can only be retrieved under the same set of contexts.

One way to understand how this can happen is to view the knowledge that children do have as encapsulated within its own microstructure, so that its accessibility is tied to a specific set of conditions. One of the best examples of this, I think, is provided by Lawler's (1981) anecdote. Lawler noted that his daughter knew how to do mental calculation with money. She also knew how to do mental arithmetic involving pure numbers by breaking them into multiples of ten and counting up the remainders. She did not, however, connect the two techniques. For example, when asked to add 75 and 26 in terms of money, she could do so by saying "that's three quarters, four, and a penny, a dollar one" (p. 4). On the other hand, when she was adding them as numbers, she did it by adding tens and counting the remainders, such as "seventy, ninety, ninety-six, ninety-seven, ninety-eight . . ." (p. 4). Lawler (1981) refers to these separate skills as "microworlds." Although they both required the same skill in arriving at the sum by counting the leftover units, the two microworlds had distinct conditions for their activation. Only later did Lawler observe moments of *insight* when his daughter first noticed that she could combine her tens microworld with her money microworld. In a previous paper (Chi & Rees, 1983), we interpreted this data as supporting the notion of access. That is, even though the two skills might seem to an adult to be part of the same skill, to a child, they are actually separate. Access to the money microworld is limited to situations where money is explicitly mentioned, and access to numerical addition is accomplished when actual numbers are presented. One could interpret the data as showing that there are two *microstructures* (localized coherent knowledge structures) that are complete and coherent in and of themselves. Structural change can be viewed as the combining of two microstructures in some way. The critical issue is how this combination or *insight* takes place. This is the universal problem of generalization and transfer. (I prefer to use the term microstructure because my research tends to focus on the structure of declarative knowledge, whereas the term *microworld* has more of a procedural skill connotation. I will use the two terms synonymously when the knowledge domain is not clearly declarative or procedural.)

Another excellent example of lack of access that can be interpreted by an encapsulated microstructures view comes from the work on adults' misconception of the physical events in their everyday world. Much current research has shown that adults have very naive views about motion, thinking that there could be no motion without a force continuously acting on it, which violates Newton's laws. What they basically possess is the pre-Galilean impetus theory (McCloskey, 1983). The fact that students' misconceptions are resistant to change, even after having taken a course in Newtonian mechanics, suggested to McCloskey that in order to learn mechanics, students must undergo major theory change—one from Galileo's theory to Newton's theory. That is, because students continue to obey the same intuitive naive theory in making predictions about motion even after having had instruction in Newtonian theories, suggested that they have not revised their existing theory. An alternative interpretation is that students have two separate microstructures. In one, the naive theory of motion, as gained from everyday observations in real world events, obeys laws proposed by Galileo. Hence, when the student is asked to make predictions about motion that mimic everyday motion seen in the real world, his intuitive theory microstructure is accessed, and predictions are made on the basis of that microstructure. When in the classroom, however, confronted with solving textbook problems, the student activates another microstructure, one that was built from lectures and textbooks. Thus, in problem solving, this microworld with Newton's three laws is activated and used.

In order for the two microstructures to merge, I suggest that sufficient instruction must occur that forces direct confrontations between the two microworlds. That is, perhaps the conditions that would activate the one microstructure be presented in a way that request the procedures for solution from the other microstructure. This has not been the case in regular classroom instruction, which usually focuses on sterile problems, where the external world has no friction and objects have no mass.

What have we gained by saying that the reason the appropriate knowledge is not accessed is because it is encapsulated in a separate microstructure, one that is not activated by the current set of conditions? How is this interpretation any different from just saying that the relevant knowledge is not accessible, or that a major reorganization (or theory change) has not taken place? I think the advantage of using the encapsulated microstructures notion is that it presents a more concrete problem for us to solve. If we view children and beginning students' knowledge as encapsulated in microstructures, then our problem becomes one of discovering ways that can foster an integration of the two microstructures; as well as one of discovering ways of representing knowledge that can depict such reorganization. With the alternative interpretation, it's not clear how one can improve the accessing mechanism, nor foster a theory change in a general way (one in which the old theory has to be replaced by a new theory). In fact, our view of microstructures sometimes obviates the need for a definition of radical restructuring (or theory change).

The definition of radical restructuring is that (1) successive conceptual systems or theories do not have a one-to-one mapping for a set of core concepts; (2) the domain of phenomena accounted for is also different in different conceptual systems; and (3) the nature of acceptable explanations is also different (Carey, 1985). A popular example to illustrate radical restructuring in the history of science is the difference in Aristotelian and Galilean theories of mechanics. For example, Aristotle did not distinguish between average velocity and instantaneous velocity, whereas this (see insert) for Galileo. Thus, the two theories do not have a one-to-one mapping in its basic set of core concepts.

Insert:
distinction was a key insight

Further, Aristotle considered both artificial motion (the movement of a person) as well as natural motion (such as objects falling to the earth); whereas Galileo restricted the phenomena of study to movement through space, and did not distinguish the two kinds of motion. Thus, the kind of phenomena the two theories explained were also different. Finally, different conceptual theories accept different sorts of explanations. Radical restructuring also requires the assumption that an alternative theory must be abandoned in order for the new theory to be functioning. This is a strict restriction. It is not clear that one necessarily needs to make this assumption. It is possible that large elements of one theory can be integrated with elements of another theory that may have been encapsulated (Case, 1985); or alternatively, a large number of elements of one theory can become less prominent as other elements become more salient and accessible, in the transition of one theory to another.

Consider a contemporary example that we all understand. Let us take theories in psychology in a restricted domain—memory. There are two kinds of theories that have been popular in the last decade, the information-processing approach and the levels-of-processing approach. The two theories have different core concepts: processes versus levels. The two theories explain different phenomena: Information-processing theories explain a number of phenomena, ranging from memory recall to problem solving, whereas the levels-of-processing approach concentrates on the phenomenon of incidental recognition memory. And the explanations acceptable to the two theories are clearly different: One concerns the length of time one spends to arrive at a response, the other explanation centers on the notion of whether one is focusing on the semantics or the visual feature of a word, independent of the amount of time. Since the two theories satisfy the definition of theory change, and both can be encoded by the same psychologist, to what extent then does the cognitive structure of a psychologist need to undergo radical restructuring in order for the psychologist to understand both theories? In some sense, the logical thing to conclude is that both theories can coexist in parallel (probably in separate ~~misconstructures~~ microstructures), and each theory can be used to interpret a set of phenomena at will. Thus, this example illustrates the possibility of using an encapsulated microstructures notion (instead of the idea of radical restructuring) to interpret the phenomenon of theory change.

CHILDREN'S MISCONCEPTION OF ANIMISM

One can always argue that knowledge is not retrieved because it was not stored properly. Such handwaving is not very convincing. To make the point one must: Either show that those children who can retrieve the knowledge have it stored *differently* than those who can't, or show that those who can retrieve it properly *stored* it properly in the first place. I shall discuss some very preliminary data to illustrate both points.

A phenomenon that has been explored for several decades concerns young children's misconceptions in attributing life to inanimate objects. According to Piaget (1930, 1951), children move from a naive stage in which they attribute human qualities to inanimate objects, to the final stage in which they can accurately discriminate living from nonliving things. In the second developmental stage, children restrict this animistic view only to objects that move; in the third stage, they make this attribution only to objects that move autonomously. Finally, they reach the mature stage of discriminating biological from inanimate objects. Piaget's view has been substantiated by a number of investigators, using an interviewing and explanation-type of data.

The kind of causal explanations given by children to questions posed by Piaget are very robust and easily replicable. For example, Piaget interviewed an 8-year-old (Zimm, cited in Piaget, 1951) and asked him "Is a cloud alive?" and he answered "Yes," "Why?", "It sometimes moves." Thus, this child is classified at the second stage of animistic thinking.

Since Piaget's research there has been abundant study, both replicating and extending Piaget's results (Laurendeau & Pinard, 1962), as well as clarifying and posing alternative explanations for his results. Berzonsky (1971), for example, showed that young children are more accurate in their discrimination of animistic from nonanimistic objects if the objects are familiar to them. Carey (1985) explained that children's life attribution results from their organization of biological knowledge, which centers on humans as the prototype of living things. There is also research which proposes a process model to try and predict children's answers (Richards & Siegler, 1984). Different tasks (other than explanations) have also been used to assess children's knowledge. Keil (1979), for example, found that children as young as 4-years-old could judge that a sentence is anomalous if it violated the animacy restrictions. Golinkoff and Harding (1980) showed that even 12-month-old infants will show surprise when inanimate objects that are usually stationary show spontaneous movement. Hence, the majority of the research either tries to replicate Piaget's finding, explain the sources of children's responses (such as biological knowledge or familiarity with the objects), proposes a process model to predict children's responses, or attempts to demonstrate that children much younger than the ages Piaget suggested were able to discriminate living from nonliving things.

There is no doubt that all the evidence accumulated thus far is true to a large extent. It is not difficult to conceive of children being more able to discriminate living from nonliving objects if they are familiar with the objects, or that they have increasing biological knowledge as they mature, or that the complexity of the task determines the reliability of their responses, or the type of responses required (articulation versus discrimination) determines the kind of answers children give. The goal of our research is slightly different. We want to understand *why* children produce the responses that they do, and why under alternative questioning probes, they produce alternative answers. The thesis of this paper is

that the answer that one gets depends on what concepts are accessed in memory, and consequently what alternative concepts are activated. We propose two explanations. First, that the response a child gives depends on what concept node is activated in memory; and second, that the extent to which related concepts are activated and thus accessed depend on the degree to which they are associated and linked. These ideas will be expanded in what follows.

A critical set of intriguing experiments is the study by Gelman, Spelke, and Meck (1983). They first developed a taxonomy of what constitutes animism, at least for people. There are four sets of properties:

1. self-initiated actions (such as can kick, see, run, talk, hear, breath, eat)
2. has parts (such as head, feet, mouth, stomach)
3. be in a state (such as feels happy or sad, remembers, thinks)
4. can perform reciprocal action (such as returning conversation, a hug, or play).

Furthermore, Gelman et al. wanted to avoid anomalous questions such as, "Does the sun know where it is going?" as well as psychological states such as volition and thinking that young children may not understand, as well as use objects that are very familiar to the child, such as people, doll, rock, puppet, and cat. Basically, they found that children as young as 3- and 4-years-old can discriminate and answer appropriately whether certain objects can do the things listed in the taxonomy, such as run, has parts, perform reciprocal action, and so on. For example, a child of 49 months can correctly answer the questions "Can a doll run?" "No." "How do you know?" "Because she is just pretend." "Can people run?" "Yes." "How do you know?" "Because their legs grow big." "Can rocks?" "No." "How do you know" "Cause they don't have any legs or feet."

The general conclusion made by Gelman et al. (1983) was that preschoolers can clearly distinguish between animate and inanimate moving objects, such as cat and puppet. This suggests that preschool children do have organized knowledge about animate and inanimate objects that they can use to correctly classify objects. The issue of concern here is whether this result contradicts those found by Piaget. Put another way, what is the organization of a child's knowledge that will produce responses such as those gathered by Gelman et al., as well as those collected by Piaget? What kind of evidence do we need to convince ourselves that young children do have an *implicit* understanding of living things vs. nonliving things? (By *implicit* understanding, we mean that a child's responses are systematically governed by principles that discriminate living from nonliving things.) To answer such questions, we began by replicating both Piaget's type of responses and Gelman et al.'s type of responses, to see if they can be generated by the same children.

Procedure

There are four parts to this study. Each part consists of a set of questions that are asked in a given session. Each of the four children in this study came in four times, spanning a 2-week period. The ages of the children ranged from 4:8 to 5:10 years.

Session 1 constitutes three sets of questions. The first set (Question 1a) asks for definitions of what it means to be alive. The second set (1b) asks children to name objects that are alive. Then, using the objects that each child named, the child was asked to explain why the named object was alive. Session 2 is a set of questions that attempt to replicate Piaget's findings. We basically asked the same kinds of questions that Piaget asked, such as "is the sun alive?", and asked for explanation. In Session 3a, 4 objects are used to assess whether children thought they were alive. These four objects were: a blob of clay, a mechanical toy cat that moved, wagged its tail, and squalled, a doll, and a pair of shoes that can be wound up to walk. These items were carefully chosen to satisfy several constraints. The blob of clay was used because we wanted a nonliving object to be attributeless so that the child would not respond to any specific attribute that the object has, and also to see if the child would endow certain attributes to it. The mechanical cat was used because it resembled a cat but is nonliving. A doll was used because even though it resembled a living thing, it did not move. And the pair of walking shoes was used because it moved, but did not resemble any living things. We asked children not only whether each of these things are alive, but also why if they said it was, as well as what could make it alive if they said it wasn't. The idea was to get at what they consider to be salient features in determining that an object was or was not alive. Notice that the questions from Sessions 1, 2, and 3a focused on the word "alive."

Questions from Session 3b, 3c, and 4 concentrate on attributes of living things, rather than probing the concept *alive* directly. So, in some sense, they are more analogous to the type of questions Gelman et al. would ask. Questions from 3b require the children to list objects that possess certain living or nonliving attributes (e.g., Tell me all the things you know that can eat and can breath). Then in Session 3c, living things (e.g., flower, trees, and tiger) and nonliving things (e.g., table, lightbulb, and clothes hanger) were chosen to be probed more specifically about attributes that they might or might not have. Each of the living objects probed were selected from each child's own responses. Therefore, for Subject 1, because she had named in a previous session that flower and trees are alive, we probed her with those things in this session. The nonliving objects probed were chosen from a subset of the subjects' pooled responses, because some the children did not list enough nonliving exemplars. These attributes fall into the classes that Gelman et al. devised; namely, that of biological properties (Can a flower grow?), states (Can a flower feel pain?), and possession of parts (Does a flower have a brain?). The basic idea of this set of questions is to see what each child knows about individual characteristics of a living and a nonliving

thing, and whether this is related to their concept of aliveness. Based on Gelman et al.'s data, we would predict that children sampled in this study would correctly know many of these attributes. The point then is, how do we resolve the discrepancy between their knowing of these attributes and their false beliefs that the sun is alive. Session 4 extended the questions in Session 3c, but focused only on human attributes. All the questions are listed in Table 8.1.

Results

One of the main points that Carey (1985) makes is that developmental changes in the concept of *alive* has to do with reorganization of biological knowledge. That is, from the ages of 4–7, biological properties such as breathing, eating, sleeping, having internal organs, are only known about people, and people are children's prototypes of their *animal* category. Therefore, whether a particular animal has or does not have a given property is judged by the similarity of the animal to people, if people serve as the prototype. Indeed, in Carey's data, she found that children are more likely to attribute an animal with having a novel property (such as an omentum), the more similar the animal is to people. Conversely, the properties that are true of animals are not said to be true of people, mainly because the reference point is people, and the attribution is unidirectional. Carey's main point is that with learning and experiencing, children undergo a reorganization in which the child's initial knowledge of what are biological properties is organized around his knowledge of people, then eventually children acquire accurate biological knowledge. Carey takes this as evidence for restructuring, at least in the sense of the novice-to-expert shift. Restructuring in the sense of the novice-expert shift (henceforth called weak restructuring) has three characteristics:

1. the experts have more concepts of the domain, but do share similar concepts with novices (that is, there exists a one-to-one mapping for a subset of the concepts);
2. the experts represent different relations among the concepts that novices do not represent;
3. these new relations that are represented by the experts permit new patterns of interrelations to occur, so that the experts' structures will necessarily be more coherent than the novices.

I would like to first confirm that children's knowledge about biological properties and people properties is acquired with learning. In addition, this reorganization appears to be a cumulative process, further emphasizing that the shift or reorganization is one of the novice-expert shift kind, not one of radical restructuring. Table 8.2 shows the responses given by the 4 subjects. The responses of the two older children (*S1*, *S2*) are shown in the top left panel and the right

TABLE 8.1
Sets of Questions Given in the Four Interview Sessions

Animism

SESSION I: Preliminary Questions

Part A--Definition

The child was asked the following five questions as a preliminary probe of his/her distinction between animate-inaminate.

1. What does it mean to be alive?
2. How do you know if something is alive?
3. What are living things like?
4. What are nonliving things like?
5. How are living things different from nonliving things?

Part B--Name Object

The child was asked to name examples from both the living and non-living categories:

Example:
Tell me some things that are alive.
Tell me some things that are not alive.

Part C--Explanation

In reference to those examples that the child named in the previous section as belonging to either the living or nonliving category, the child was asked:

1. Why is X alive?
2. Why is Y not alive?

SESSION II: Replication of Piaget Experiment

In this session the child was asked questions typical of the type used in Piaget's animism research.

Example: Is the X alive? Why or why not?

Probes for X: sun . mountain . cloud.
wind . stone . tree.
flowers . bicycle . fire . fly.
horse . goldfish . you . lake

SESSION III: Life Attribute Questions

Part A--Life Attributes

Following each stimulus presentation the child was asked to judge if the stimulus was alive or not alive and what attributes determine the distinction.

Example: Is X alive? What makes it alive or not alive?

Probes for X: blob of clay.
moving mechanical toy cat.
talking doll.
walking mechanical toy shoes.
a potted plant

Part B--Replication of Carol Smith's Experiment

The child was asked to name examples which possess properties associated with animate or inanimate objects (but not both).

Example: Tell me all the things you know that X.

Probes for X: have babies and breath.
grow and have a heart . melt.
have roots and can die . have bones
and a brain . need gasoline.
eat and die . feel pain and
can talk . have wheels.
see and go pee pee . get rusty

(continued)

(Table 8.1 continued)

Part C--Life Attributes

The child was asked to judge if the items named in Session I possess properties associated with living.

Example: Does a clotheshanger X?
Does a tiger X?

Probes for X: eat . have babies . grow.
have a heart . have bones.
have a brain . have roots . die.
talk . see . go pee pee.
feel pain . cry

SESSION IV: Human Attributes

The child was asked to judge if the items in Session I possess human attributes.

Example: Does a clotheshanger have a X?
Does a tiger have a X?
Does a tree have a X?

Probes for X: heart . intestine.
brain . muscles.
bones . blood . feet.
arms . legs . nose.
ears . mouth . eyes.
face

panel shows the responses of the two younger children (*S*3, *S*4). Each child's responses from Session 3c are divided into 4 cells. The top two cells are responses to living things, and the bottom two cells are their responses to nonliving things. The left cells are characteristics of people, and the right cells are characteristics of living things (or biological properties). There are two things to note. First that, as children mature, they acquire more knowledge about what are the biological properties of living things. This can be seen by the fact that both of the mature children (*S*1, *S*2) responded correctly that the living things possess biological properties, (that is, none of the upper-right-hand cell has a "no" response, as indicated by a 0) whereas both of the younger children (*S*3, *S*4) lack some knowledge about biological properties that animals possess (see Insert A)

The second thing to note is that none of the children attribute nonliving things as having properties of people or biological properties. (That is, none of them answered "yes" to questions such as "can a table die?" as depicted in the lower 2 cells of each subject's responses. See Table 8.2 again.) This suggests that they may have an *implicit* understanding of what things are living and what things are not. (See Insert B) associated with each. (By *implicit* understanding, we also mean an understanding that is not accessible in standard explanation paradigm where a reason has to be articulated.) Although this evidence is not conclusive, we will discuss what alternative data should be gathered that can be more convincing.

If it is the case that children do have an implicit discrimination of living from nonliving things, why do they then make the mistakes of saying things like "The sun is alive" or, that "It's alive because it moves?" Also, why are they not able

Insert A: (for example, S3 did not know that a giraffe breathes).
Insert B: on the basis of which set of properties are

TABLE 8.2
Responses of the Four Subjects in Session III: Part C--Life Attributes

X = Yes
O = No

Subject		Stimulus	heart	see	talk	brain	pain	cry	bones	roots	die	reproduction	breath	grow	excrete	eat
			CHARACTERISTICS OF PEOPLE								CHARACTERISTICS OF LIVING					
S#1	LIVING	ant	X	X	O	X	X	O	X	O	X	X	X	X	X	X
		tiger	X	X	O	X	X	O	X	O	X	X	X	X	X	
		caterpillar	X	X	X	X	X	X	X	O	X	X	X	X	X	X
	NONLIVING	table	O	O	O	O	O	O	O	O	O	O	O	O	O	O
		lightbulb	O	O	O	O	O	O	O	O	O	O	O	O	O	O
		hanger	O	O	O	O	O	O	O	O	O	O	O	O	O	O
S#2	LIVING	bird	X	X	O	X	X	O	X	O	X	X	X	X	X	X
		turtle	O	O	O	O	X	O	X	O	X	X	X	X	X	
		people	X	X	X	X	X	X	X	O	X	X	X	X	X	X
	NONLIVING	table	O	O	O	O	O	O	O	O	O	O	O	O	O	O
		lightbulb	O	O	O	O	O	O	O	O	O	O	O	O	O	O
		hanger	O	O	O	O	O	O	O	O	O	O	O	O	O	O
S#3		giraffe	O	O	O	O	X	O	O	O	X	X	O	X	O	X
		clam	O	O	O	O	O	O	O	O	X	O	O	O	O	
		shark	O	X	O	X	O		X	O	X	X	O	X	O	X
		table	O	O	O	O		O	O	O	O	O	O	O	O	O
		lightbulb	O	O	O	O	O	O	O	O	O	O	O	O	O	O
S#4		flower	X	O	O	X	X		X	X	X	X	X	X	O	X
		tree	X	O	O	O	O	O	O	X	X	O	O	X	O	
		tiger	X	X	X	X	X	X	X	O	X	X	X	X	X	X
		table	O	O	O	O	O	O	O	O	O	O	O	O	O	O
		lightbulb	O	O	O	O	O	O	O	O	O	O	O	O	O	O
		hanger	O	O	O	O	O	O	O	O	O	O	O	O	O	O

*Blank spaces indicate that the experimenter did not probe for an attribute.

to discriminate between animate and inanimate objects, and yet be able to correctly state that "A tiger can eat or sleep," etc. The answer to these two questions may lie in the way the knowledge is represented, and what part of the knowledge structure is accessed. To illustrate this point, we present a representation of (1) our most naive subject, (2) our most sophisticated subject, and (3) an adult subject.

A semantic network representation of nodes and links is constructed using the protocol data from Sessions 1, 2, and 3a. The semantic nodes are derived from actual concepts the child used, and the links are relations that are derived from what they generate. For example, if the child said, in response to the question "What does it mean to be alive?" "It means to be alive . . . mmm . . . let's see . . . it means to be happy too", then, we would construct two nodes—an "alive" node and a "happy" node, and link them with the relation *state*. To simplify the network, we prefer to ignore the characteristics of the relations between the nodes and simply depict that a link exists. Our only constraint, one that is common among semantic networks, is to assume that there are no redundant concept nodes, unless these nodes are associated with concepts that are embedded within a different microstructure (to be elaborated later).

Figure 8.1 captures the gist of the representation of the concepts "alive" and "not alive" of our most naive child, who was 4:8 at the time. (What has been left out are additional instances and attributes that have been mentioned infre-

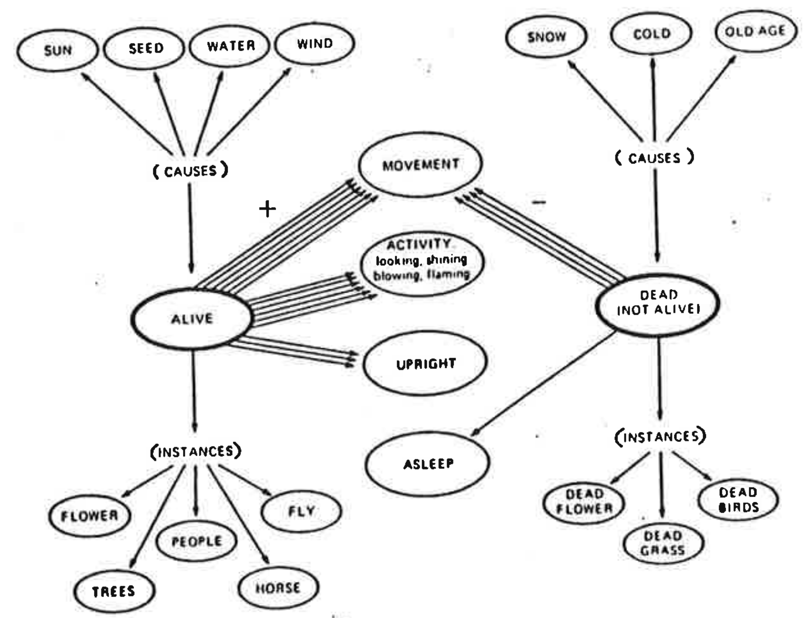


FIG. 8.1. A representation of the most naive child's knowledge.

quently.) For this child, there is a clear error in the mapping of the semantic of the word "not alive" to the word "dead." That is, things that are not alive are things that are *dead* rather than inorganic. And also *dead things* do not have motion, and the causes of "not aliveness" are old age, cold (that is, freezing temperature), and snow. And instances of things that are not alive are dead things, like "dead birds" and "dead flowers." And, as Piaget correctly stated, this child's salient attributes for things that are alive versus things that are not center on motion and activities. (When an attribute such as "movement" is shared by both the "alive" and "dead" concepts, as shown in Fig. 8.1, positive links depict that the concept possesses that attribute, whereas negative links mean that it was explicitly mentioned by the subject that the concept does not have that attribute.)

Aside from the error in semantic mapping, this child's knowledge structure is not only meaningful (in the sense that alive things generally do have motion or can generate activity, and dead things cannot), but we further propose that this child's knowledge structure, although naive, is quite coherent in and of itself. By coherent, we mean that the two primary concepts—alive and dead—are highly integrated, as evidenced by the large number of shared attributes, especially in an inclusive and exclusive way. That is, alive things are those that have activities or have motion or are upright, whereas nonalive or dead things have the opposite attributes, which are those that have no motion or activities, and are asleep or lies down. And finally, the child has a fairly clear set of causes for what makes something alive (water, sun, seed) and what causes somethings to die (old age, snow, cold temperature).

We have proposed elsewhere (Chi & Koeske, 1983; Gobbo & Chi, 1986) that a coherent structure is one that has many shared attributes between the key concepts. In the domain of dinosaurs, for example, expert children tend to use the presence and absence of a few salient features to decide whether a dinosaur is a meateater or a planteater. Hence, a dinosaur is a meateater if it has "long" and "sharp teeth," whereas it would be a planteater if these features were absent. Novice children of the same age (i.e., children who have less knowledge about dinosaurs), would have one set of attributes to decide whether a dinosaur is a meateater or not, and a separate set of attributes to decide whether or not it is a planteater. The use of one set of features to contrast two categories (meateaters and planteaters) suggested that the two categories are more coherently integrated in the expert children's knowledge representation than in the novice children's knowledge representation. This same characteristic of coherence is seen in our youngest subject's representation of dead and alive, suggesting that they see the two concepts as bipolar opposites.

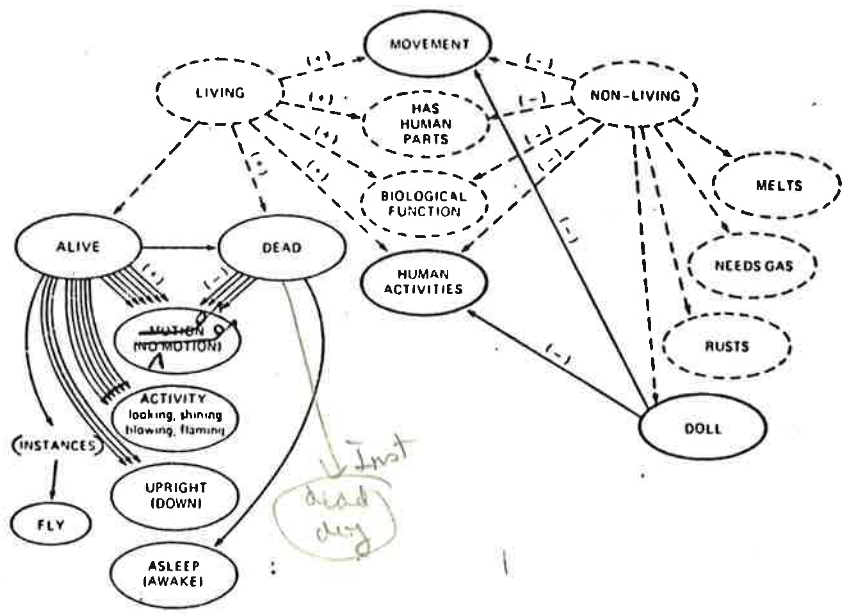
An important question we want to answer from this representation is how we can understand why a given child can simultaneously answer Gelman et al.'s (1983) questions ("Can you run with a doll?" "No."), and yet incorrectly answer Piaget's question ("Is the mountain alive?" "Yes." "Why?" "It is

when it makes a noise"). Our interpretation of such data is the following. From the representation of the child's protocol in Fig. 8.1, we can imagine that the child has never encountered such questions before, nor encountered such statements, so that such knowledge could not have been prestored. Therefore, in order to sensibly answer this question, the child must search the attributes in her representation that are associated with the "alive" concept, and postulate that the mountain is alive if it produces certain activities (such as making noise), because having the capability of producing activities is an attribute of aliveness for her. Her response protocols generally fit this characteristic—namely that she will postulate an attribute which is true of *alive* things, and state that the object in question is alive if it has that attribute. So for example, when we asked "Is the stone alive?", the child responded "Yeah." "Why is a stone alive?" "Because when it rolls I know how it is alive." (Presumably rolling is an activity that a stone is capable of producing. Therefore it is alive.)

What about the fact that the child can answer the Gelman et al.'s questions correctly? An ideal interpretation is to say that the reason the child can answer them correctly is because she has an implicit understanding of the concept of nonliving things, and one cannot do these things with nonliving things. That is, this interpretation would assume that the child has a hierarchical branch of nonliving things, as is shown in a hypothetical network (see Fig. 8.2, the portion of the semantic net that is depicted by the dotted lines). However, I think this would be endowing the child with greater understanding than is necessary. From such data, all one can really conclude is that the child has a "doll" node somewhere in memory, and associated with a doll node are attributes such as "a doll can't run on its own," "a doll can't talk unless there is a string to pull," and many others. So, when the child is confronted with a question such as "Can you run with a doll?", the child knows enough about properties of dolls to answer that question correctly. The concept of "doll" need not necessarily relate to their conception of living and nonliving things.

One additional thing we want to point out about Fig. 8.2 is that we believe redundant nodes do exist if ~~it is~~ they are embedded within a different microstructure. We conceptualize the "alive" and "dead" nodes as embedded within a localized coherent structure (the solid lines), and *movement* is an attribute discriminating dead from alive; yet we hypothesize that it is also an important attribute that people use to discriminate living from nonliving. Therefore, it is conceivable that movement can be represented by two separate nodes in this hypothetical network.

What kind of evidence do we need in order to be convinced that the child is sensitive to a distinction between living and nonliving things? That is, how can we assess the extent to which this child has a representation corresponding to the nonliving (dotted) branch for the tree, as shown in Fig. 8.2? One critical set of questions that we did not ask, which could provide such an assessment, would be to query the child about differences between dead things and nonliving things.



Movement
(No Movement)

FIG. 8.2. A hypothetical representation embedding what the most naive child knows (the solid lines, taken from Fig. 1), with knowledge that the child presumably will acquire (the dotted lines).

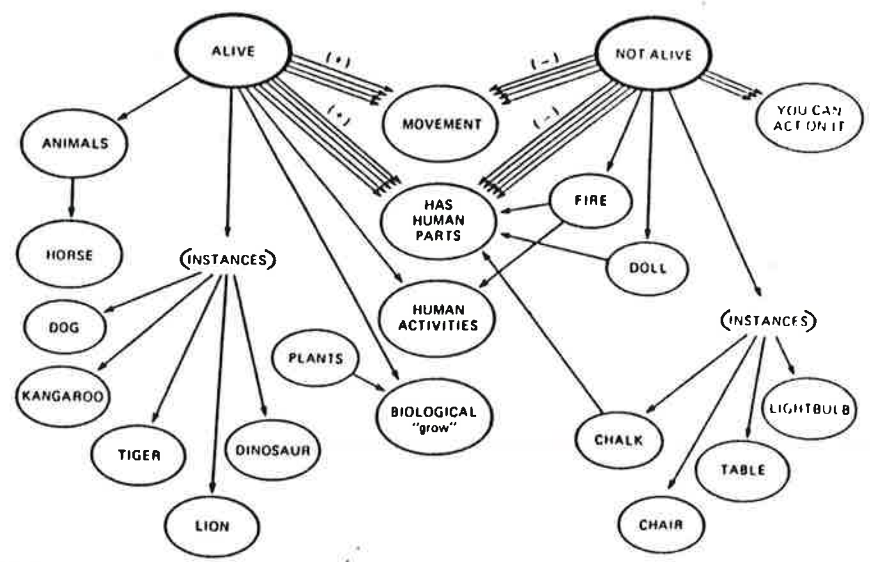
For example, we could use an attribution paradigm of Carey's (1985), and ask the child questions such as: "If a dead cat has an omentum, would a tin can have it, versus would a bird have it?" We would predict that a child who is sensitive to the difference between living and nonliving objects would have a barrier in his or her pattern of attribution so that it would not cross the boundary between the left (LIVING) branch and the right (NON-LIVING) branch of Fig. 8.2.

Although we argue that this child's microstructure of *alive* and *dead* concepts are fairly structured, coherent, and intact, what has to happen in order for this child to achieve the more mature structure in which she will correctly comprehend and discriminate living from nonliving things? Without looking at a more sophisticated subject's data, we can hypothesize that a more sophisticated structure would contain attributes that link the living with nonliving concepts in a contrasting way. Some of these shared attributes would initially be the characteristic ones, but with accumulation of greater biological knowledge, the child would come to learn the critical defining attributes.

Our oldest child subject's knowledge is represented in Fig. 8.3. Again, we did not try to capture all the utterances that she stated. But this partial representation does capture the gist of her statements. There are several major differences between her representation and that of our most naive child's (as shown in Fig.

8.1). First, this child does not map the word "not alive" onto the semantic of "dead." She correctly interprets not alive as nonliving, basically because she names the right kind of objects (such as doorknobs, clotheshanger) when we ask her for things that are not alive. Second, this child definitely uses human attributes (both human parts and human activities) as a critical feature to discriminate living from nonliving things, and movement alone is no longer a sufficient criterion. (In this representation, we indicated positive attributes with a plus sign and negative attributes with a minus sign at the links.) So for example, for this child, she claims that a cloud is not alive, and when asked why, she says "Cause it can't move. Well it can move by the wind. It can't talk. It doesn't have a face. It doesn't have a body. . . ." Therefore, she answered Piaget-type questions correctly because these objects (mountain, sun, wind, etc) do not possess human attributes or cannot perform human activities, even though they sometimes can move or can be moved. We further know that people and animals are her primary prototypes of living things because when asked "What would a flower have to be like for you to know it is alive?", she answered "Like a person. Or like a cat or a dog or an animal."

A third characteristic of her representation is that, although it is very coherent (that is, living things and nonliving things are contrasted by basically the same set of attributes), she has not acquired the defining attributes of living things (that is, the biological functions). Because *having human attributes* is still such a strong feature of living for her, she is just at the stage where she cannot resolve



missing from this repres: (People) node

FIG. 8.3. A representation of the most mature child's knowledge.

the conflict about whether or not plants are alive. So for example, she claimed that flowers are not alive, and when probed why, she said she didn't know. But when we pushed her, as we saw earlier, her reason was that because a flower has to be like a person or an animal in order to be alive. Later on in the protocol (session 3a), when asked if a given plant is alive, she first said no, then changed her mind, and then gave the reason that "Well, it's almost like a person . . . It can grow by itself, you have to water it. . . ." So, she is beginning to acquire some biological attributes of living things.

Figure 8.4 is a representation of an adult subject. Notice that the main attributes that this adult uses to contrast living from nonliving things are biological properties such as respiration, digestion, excretion, reproduction, growth, and movement. Thus, *having human attributes* and human activities which are present in the mature child's representation that was shown in (Fig. 8.3), have essentially been omitted in this adult's representation.

WHAT IS KNOWLEDGE REORGANIZATION

Having seen three representations of the concept *alive,* what can we say about what is knowledge reorganization? What does it take to reorganize the knowledge of the sophisticated child (Fig. 8.3), to the knowledge of the adult subject (Fig. 8.4)? Our data is consistent with that presented by Carey, namely that children's primary prototype of living things focuses on people attributes (such

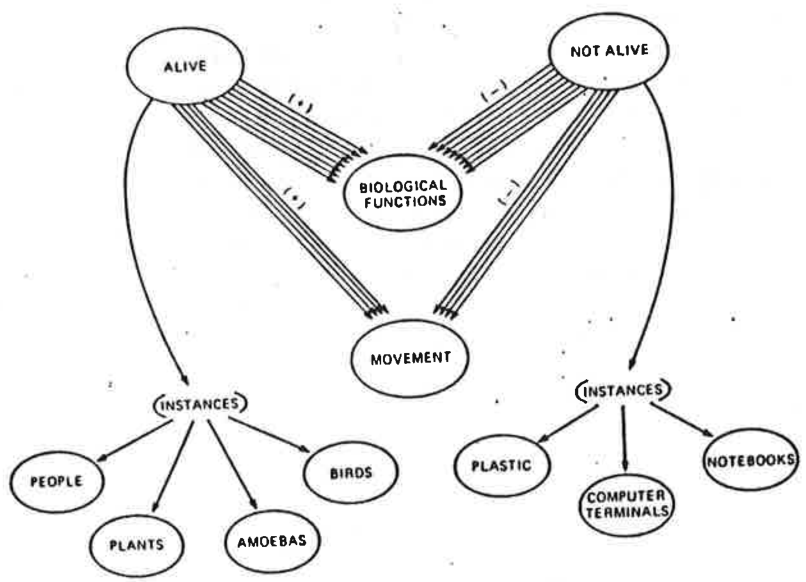


FIG. 8.4. A representation of an adult's knowledge.

as having human parts and human activities), but eventually they change or *reorganize* their knowledge so that the critical attributes contrasting living from nonliving things are biological functions. The critical issue is, how does this knowledge reorganization take place? Is the mechanism of restructuring a weak or radical one, as defined earlier?

From our data, I think we can postulate that the restructuring is a weak one. How can this take place? Well, one can imagine an incremental process by which children encounter a greater and greater number of instances of living things that do not have human parts, either through textbooks or being told. Therefore, over time and experience, the links associating living and nonliving things with "have human parts" or "have human activities" will not increase, whereas there will be an increasing number of links with the attributes of "biological function". This is not to say that the attributes of having human parts and human activities will actually be deleted from the knowledge structure, but only that these attributes will no longer be salient, in comparison to the build-up of biological functions as a salient attribute.

We know that characteristic features are not deleted from the knowledge representation because they are often cited to explain why an object is or is not alive. This may be because it is often easier to explain by using characteristic features than to cite the defining ones, especially when the defining ones are not robustly represented by the subject yet. So for example, even our adult subject first acknowledged that she knows that something is alive because "Uh, let's see, by movement," then elaborated by saying that "that's one way, except there are living things that don't move." Similarly, our sophisticated child subject, when asked why she thinks the wind is not alive, answered "Cause it doesn't have a face, and you can't see it, and but it can move." Therefore, the reorganization is a weak one in that additional concepts and links are accumulated over time, and this accumulation results in a different pattern of *emphasis* on the salient attributes. Some subset of core concepts are maintained, and the old theory (that something is alive because it moves) is abandoned, but it is not deleted. It is *abandoned* in the sense that it is not accessed, because a more salient set of attributes which can critically discriminate between living and nonliving objects has emerged and is accessed because of its dominance.

What about the reorganization from the most naive child's data (Fig. 8.1) to the more sophisticated child's data (Fig. 8.3)? What constitutes reorganization in this case? Although we do not have the critical data to defend our hypothesis, we can speculate and say that in order for the child to develop the structure in Fig. 8.3 from Fig. 8.1, the child must acquire additional structures (the dotted parts of Fig. 8.2), but the original microstructure of "alive" and "dead" remains intact. (That is, we believe that the dead–alive microstructure—the solid lines of Fig. 8.2, is available and present in the representation of the child's knowledge in Fig. 8.3. We cannot be certain that this is true because no data was gathered to query that part of the knowledge structure.)

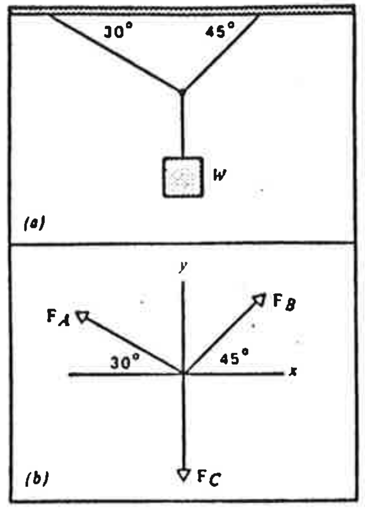


Figure 5-6 Example 5. *(a)* A block of weight *W* is suspended by strings. *(b)* A free-body diagram showing all the forces acting on the knot. The strings are assumed to be weightless.

1. Figure 5-6a shows an object of weight W hung by massless strings.
2. Consider the knot at the junction of the three strings to be "the body".
3. The body remains at rest under the action of the three forces shown Fig. 5-6.
4. Suppose we are given the magnitude of one of these forces.
5. How can we find the magnitude of the other forces?
6. F_A, F_B, and F_C are *all* the forces acting on the body.
7. Since the body is unaccelerated, $F_A + F_B + F_C = 0$
8. Choosing the x- and y-axes as shown, we can write this vector equation as three scalar equations:
9. $F_{Ax} + F_{Bx} = 0,$
10. $F_{Ay} + F_{By} + F_{Cy} = 0$
11. using Eq. 5-2. The third scalar equation for the z-axis is simply:
12. $F_{Az} = F_{Bz} = F_{Cz} = 0.$
13. That is, the vectors all lie in the x-y plane so that they have no z components.
14. From the figure we see that
15. $F_{Ax} = -F'_A \cos 30^\circ = -0.866F_A.$
16. $F_{Ay} = F_A \sin 30^\circ = 0.500F_A.$
17. and
18. $F_{Bx} = F_B \cos 45^\circ = 0.707F_B,$
19. $F_{By} = F_B \sin 45^\circ = 0.707\ F_B$

FIG. 8.5. An example taken directly from a physics text (Halliday & Resnick (1974).

of the explanation. We find that students who are successful at subsequent problem solving are those who are building *rich* rules during the studying of the worked-out examples. They tend to do one of three things. They often add new relations that were not specified in the example. That is, the students add knowledge to their representations by inferring additional information beyond that presented. For example, in Fig. 8.5, which is an actual example taken from a text (Halliday & Resnick 1974), after reading Statement 3, the student said "So, that means that they have to cancel out, only the body would not be at rest." Another good student inferred, after reading Statements 4 and 5, "So the sum of the forces should be zero." It is easy to see how the rules stored by these successful students are more complete and enriched because of the additions of new relations of these kinds.

Another way that good students elaborate is to specify or expand the conditions under which a procedure is to be applied. For example, after reading Statement 8, one student said, "So it's convenient because you save one of the . . ., you put one of the axis on one of the force's . . . line, on the W force." This is an extremely important specification of the condition under which the reference frame (the coordinate axes) was chosen to be as shown in the lower panel of the free-body diagram in Fig. 8.5. The building of this kind of rule can explain why under slightly different problem conditions, the good students who have built this kind of rule can know how to choose a reference frame, whereas a poor student who did not build such a rule may associate the choice of the reference frame simply with the vertical and horizontal components of the diagram. Thus, a poor student will not know what to do in situations where the forces are slightly rotated from the ones shown in the figure. We actually have such evidence.

Notice that statement 8 simply provided the action part of a procedure (we are assuming that a procedure is a condition-action rule). Statement 8 stated only that one should choose the *x*- and *y*-axes as shown, without providing the conditions under which such a choice would be made. Therefore, what the student did in this case was to expand on the conditions under which such an action should be taken. Without providing the explicit conditions, the learner would have stored a rule that has no specific conditions attached to its action. This would create difficulties later, when the student would not know when or how one should choose a specific reference frame and what constraints to consider. In some of our previous work, we have seen evidence that unsuccessful learners have rules with no specific conditions (see also Chi, Glaser, & Rees, 1982). Expanding on the conditions of a procedure allows the good learner to build complete rules for subsequent use in a problem-solving context.

A third kind of explanation that good learners make is to recognize that a set of specific procedures serve the same goal. As a result, a procedural "chunk" is formed and the learner avoids being immersed in detail. After reading statement 14, for example, one good student said, "Now they are going to do the same thing with it to the *y*," meaning that the equations of statement 14 describe what has to be done to Force A in the y direction in the same way that it was done to Force A in the x direction in statement 13. Hence, what the student has done is define a goal of what this set of equations accomplishes, and then proceeded to elaborate on what these equations actually mean. Her subsequent elaborations were "In the y axis, and umm, they are going to say that this times sine, so x is sine, or y is sine, at this angle. And here the angle is here is equal to, yeah okay, I'll agree with that. Umm, sine 30, okay, .5 times the force." We consider the initial elaboration after reading statement 14 a way of understanding the global intent of the equations before proceeding to unpack the details. This allows the students to *see* that the next set of procedures serves the same goal and to generalize the purpose of a set of specific procedures.

The characteristics of the explanations that we have identified clearly suggest that in order for students to fully understand each statement of a worked-out example, they must explain the implications, the conditions, and the goals of the procedures. That is, they must infer what is true after reading each statement or set of statements, explain why a procedure is applied in the way specified, and apply a general goal to a set of detailed procedures. By engaging in such explanations, the good students are storing more complete rules that can be accessed and used in later problem-solving situations. For instance, by supplying and specifying the conditions under which one chooses a reference frame, a student will be more able to decide later how a reference frame should be chosen in a problem-solving situation. Hence, the success with which he or she uses and accesses that procedure depends on how it was stored initially. The actual linkage between the procedure the student has stored and whether it is subsequently used will be an analysis that we will pursue. (For other findings concerning the role of self-explanations, see Chi, Bassok, Lewis, Reimann, & Glaser, in press).

CONCLUSION

In summary, this chapter attempts to present a framework in which lack of access is seen as a mismatch between the way the relevant knowledge is actually represented, and the conditions under which it has to be retrieved. The possibilities of how knowledge can be reorganized so that it can be accessed are also proposed. Basically, the idea is that not only are new concept nodes and links acquired with experience, but a reorganization can also occur as a result of a changing shift in emphasis of what might constitute the relevant discriminating features between concepts. Such reorganization must be considered to be one of the novice-to-expert shift kind, and not a radical one.

Using the example from children's concept of living and nonliving things, we also argue that the apparent contradictions in children's ability to answer Piaget's type of questions incorrectly and Gelman et al.'s type of questions correctly has to do with how their knowledge of these concepts are represented. Mappings of two children's and an adult's knowledge, as gathered from their protocols, are presented to illustrate the point. The main idea is that responses are determined by what parts of the knowledge structure are probed, as well as what attributes are linked to the concepts. In order to decide whether children truly have an implicit understanding of living versus nonliving things, questions have to be designed to probe *not* only the local nodes, but the hierarchical structure itself. Many studies, including our own, have not accomplished this.

I have also discussed alternative ways of demonstrating that lack of access may have to do with a mismatch of the context of conditions under which the relevant knowledge is stored, and the conditions under which it has to be retrieved, by presenting another line of research that is underway. Hopefully, both tactics will converge on a better understanding of what it means to say that the relevant knowledge is there but not accessible.

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