A Somewhat Modified Version of this Chapter appears in D. Medin & H. Pashler (Eds.), (2002), Ch. 12 , Vol. 2. Stevens Handbook of Experimental Psychology.

Cognitive Development[1]

Rochel Gelman

Rutgers Center for Cognitive Science and Department of Psychology, Rutgers University

[1] Part of the material in this chapter was presented in Gelman (1998 a, b) and Gelman & Lucariello, Vol.3 of this series. Funding for the preparation of the chapter came from The preparation of this chapter was NSF grants DFS-9209741 and SRB-97209741. Send Correspondence to Rochel Gelman, Cognitive Science, Rutgers University, 152 Freylinghuysen Rd, Piscataway, NJ 08844-8020

Introduction

The challenge for students of cognitive development is to characterize how our young accomplish the task of acquiring concepts they come to share with others and communicate about. Any account also must deal with the fact that people's concepts do not stand alone, each separate from the other. Our concept of a dog is related to our knowledge of other animals and our concept of a bicycle is related to what we know about other wheeled artifacts. These facts about our mental lives are extremely important. They point to organizations that underlie our ability to generalize what we know to novel instances in the same conceptual structure, to make inferences about the meaning of names for new objects, and so on. If one is told that an Umquat is an animal, one knows immediately that this unknown creature breathes, eats, perceives, communicates, reproduces, and is self-propelled.

An Overview of Cognitive Development Theories

Theories of cognitive development differ greatly over how one should characterize the acquisition and nature of conceptual representations that can support the development of conceptual coherence and inference. There are least five different kinds of cognitive development theories.

The learning theory account is based on the assumptions of empiricism: All knowledge is due to sensory and motoric experiences and the capacity to form associations. Concepts reflect the associative strengths that are built as a function of the frequency with which contiguous sensations are experienced. Information-processing theorists focus on the roles that information-processing and problem-solving capacities play in explaining how children learn to understand the world. With experience and practice over time, children acquire memories and develop ways to circumvent processing limits on attention, short-term memory, and perception. Learning theory and information-processing accounts share the assumption that cognitive development is a linear function of experience. The sociocultural account also builds cognitive development as a linear function of experience, first as sensory and perceptual experiences, and then as conceptual and language-based ones. The social variants place emphasis on the idea that concept acquisition is facilitated by infants' inclinations to pay attention to the social agents that serve as transmitter and presenters of key information (Rogoff &Chavajay, 1995). Still, they share the assumption that the acquisition of concepts is a protracted process, taking as much as two years before a child has the ability to represent the world in terms of concepts and to communicate with others.

Some sociocultural theorists incorporate the key assumption of stage theories, that is, that development involves passage through qualitatively different stages in a given order (e.g., Vygotsky, 1962). At each stage, the child actively engages the environment with existing structures of mind to such an extent that it is possible for the child to "misinterpret" inputs. For example, in Piagetian theory, cognitive development proceeds from sensorimotor (0-2 yr), to (2-5 or 2-6 yr), to concrete operational (6-10 or 6-11 yr), to formal operational structures of mind (12 yr and more). The Piagetian child who is still at the preoperational stage will fail to conserve quantity across transformations because he or she still must acquire the structures that will support quantitative reasoning, a hallmark of Piaget's concrete operational stage. Such a child therefore cannot help but be perception-bound. Therefore, children in the preoperational stage also fail Piagetian perspective-taking tasks because they rely on their own view, which is the immediately available perceptual input.

Similarly, children at this stage use perceptual strategies in the classic tasks of number, length, and liquid conservation. Like 7- to 10-year-old children, children in the preoperational stage agree that two sticks of the same length are equal if they are placed exactly parallel to each other, that the two rows of chips are the same number if they are one above each other in perfect one-to-one correspondence, and that two identical glasses contain the same amount of water if the water lines are at the same height. However, when one of the two displays is transformed before their very eyes--the effect being to make one stick extend further to their right than the other, one row of chips longer than the other, and the water in a taller beaker higher than the initial one—preschool-aged children fail to conserve. That is, they say that each of the changed elements is longer or has more.

The notable differences among the four theories just mentioned becomes more apparent in studies of post-infancy cognitive development. For example, because scholars working in the information-processing tradition emphasize the general limits on processing, they do studies that show how success varies as a function of real-time processing demands (Siegler, 1991). Those who emphasize the social aspects of cognitive development might focus on the different cultural and conversational rules that must be acquired within a culture (Greenfield, 1997; Rogoff, 2000; Scheiffelin & Ochs, 1986; but see Siegal, 1991). Despite the fundamental differences, all four classes of theories converge on a common view about infant and preschool cognition. Infants come to the world without any mental structures that relate to the kind of conceptual, linguistic, and social world they will live. Be it from the position of empiricist learning, information-processing, or stage theory, infants first learn about sensory and action experiences. These lay the foundation for developing perceptions, that in turn are the first kinds of information used for classifying different objects. These in turn are associated, assimilated, or networked to form the framework for inducing abstract concepts. Most sociocultural accounts also share the "sensation to perception to abstraction " view of development (but see Medin & Atran 1999). However, this view adds the assumption that acquisition is facilitated, first by infants' inclinations to pay attention to the social agents who serve as transmitters or presenters of key information, and second, by toddlers' and preschool-aged children's development of linguistic communication abilities. The assumption is that this makes it possible for other social agents to work together with young children to help them create knowledge that is intricately linked to sociocultural contexts.

Thus, each of the four theoretical accounts embodies the view that children require as much as two years to begin to represent the world in terms of something like concepts. At first blush, this seems reasonable. After all, newborn infants are extremely helpless, and human infants take a fairly long time to get beyond the many limits on their motoric, sensory, and communicative abilities. That the onset of language use is delayed until around 2 years of age is consistent with the ideas that neonates' conceptual knowledge is nonexistent and that older infants' conceptual knowledge is extremely shallow. Indeed, one might ask-how anyone could think otherwise. Those who answer to the contrary do so because of the accumulating body of evidence that infants, toddlers, and preschoolers do have some remarkable conceptual competencies. Such evidence, some of which is presented later, has contributed to the emergence of a fifth theoretical account of cognitive development, one that

R. Gelman (1993) dubbed a rational-constructivist theory of cognitive development. Different authors working within this tradition adopt different terminologies. Still, they share a commitment to some combination of a rationalist and constructivist position.

The rationalist side of the theory captures the assumption that very young children and even infants bring a skeletal outline of domain-specific knowledge to their task of learning the initial concepts that they will share with others. The constructivist side of the theory captures two assumptions. First, from the start, children are active participants in their own cognitive development. Second, early cognitive development benefits from innate abstract guidelines that children use to select and learn about relevant environments. I put the matter this way: Even though children are beginning learners, skeletal principles motivate them to seek out and assimilate inputs that nurture the development of these structures for core domains such as quantity, causality, and its relation to the animate-inanimate distinction. Leslie (in press; Leslie & Scholl, 1999) talks about innate modules that draw attention to the input that can feed the theory of mind module (ToMM). S. Gelman (1996) developed the position that children have an essentialist mind regarding the acquisition of concepts about the world. She also emphasized the idea that implicit assumptions of cause help children to zero in on relevant data. (for a related view, see Ahn, 1998; R. Gelman, 1990; and Keil, 1995,). Coley, Medin and Atran (1997) distinguished between expectations and general knowledge about categories of nature, on the other hand, and detailed knowledge about the different sub-categories within these, on the other. Mandler's account of her evidence that toddlers and even infants classify animals and vehicles separately also appeals to the idea of an initial general level of categorization. Spelke (2000) wrote about core theories, especially regarding objects. There are clear differences in the way these variants of neo-nativist positions are developed. Importantly, most acknowledge that what is given to start with is but a start. It is only because infants actively use whatever skeletal structures they have that they can begin to engage, assimilate, and therefore construct domain-relevant knowledge--hence, my choice of the label "rational constructivism for this class of theories.

Like stage theorists, rational-constructivist theorists maintain that there are universal structures of mind. However, these theories differ about whether there is some innate conceptual knowledge exists. For example, although Piaget held that processes of assimilation and accommodation are innate, he denied the presence of any innate structures of mind. In contrast, the rational-constructivist position combines the assumption of innate inclinations of mind with the assumption that the mind actively processing (assimilating and accommodating) the environment with available innate skeletal structures, even if they are nascent. It also differs from stage theories in its commitment to the view that there are domain-specific as opposed to domain-general structures of mind. For example, whereas Piaget's theory grants the mind general structures such as concrete operations, this class of theories holds that different domains of knowledge involve different organizing structures.

Nothing in the preceding text requires domain-specific knowledge be built on an innate foundation. Regarding the developmental trajectory, domain-specific theorists make a distinction between s foundational or core domains that are therefore shared by all normal humans and domains that different individuals acquire (e.g., Carey, 1999; R. Gelman & Williams, 1998; Wellman & S. Gelman, 1992; Keil & Lockart, 1999). Whether a domain is core or noncore, the definition should be the same. This requirement is met by R. Gelman's (1993) proposal: A given set of principles, the rules of their application, and the entities to which they apply together constitute a domain. Different structures are defined by different sets of principles and by their related entities and combinatorial rules. Thus, knowledge of a particular kind can be said to constitute a domain of knowledge to the extent that one can show that a set of interrelated principles organize the entities and related knowledge, as well as the rules of operation on these.

The distinction between core and noncore domains is related to the novice-expert distinction, a topic of keen interest to many who work in the information-processing and computer- modeling frameworks (Chi, Glaser, & Farr, 1988; Klahr, 2000; D. P. Simon & Simon, 1978). Be it about the acquisition of noncore or expert levels of knowledge structures, a common problem must be confronted: When what is to be learned does not share a structure with what is already known, the learner has to mount a new conceptual structure. Otherwise, the risk is high that the learner will not understand the facts and procedures that are related to the domain. Thus, the problem can be restated: How do people ever acquire new mental structures, and in some cases structures that are inconsistent with those that are already part of the child's mental conceptual apparatus (Carey, 1985, 1999; Hartnett & Gelman, 1998)? That is, how do we ever get to the point where we have acquired new conceptual structures? This issue of continuity or discontinuity is not unique for domain-specific theorists. The same question remains unanswered regarding the shift in Piagetian stages from preoperational to concrete operational thought. It is the question motivating the use of microgenetic analyses of changes in knowledge (Kuhn, Garcia-Mila, Zohar, 1995; Siegler, 1996). It is deeply related also to arguments about whether one should favor a symbolic, rule-like connectionist or production-system model over a nonsymbolic connectionist model (Elman, Bates, Johnson, Karmiloff-Smith, Parisi, & Plunkett, 1996; Klahr, 2000; Marcus, 2001; McClelland, 1995). Finally, it is one of the major issues addressed by historians of science and mathematics (Kitcher, 1982; T. Kuhn, 1970) and cognitive anthropologists (Atran,1998; Boyer, 1994; Hirschfeld, 1996; Sperber, 1994).

More on Traditional Accounts and Evidence

A Preamble

I started my career as a Stimulus-response learning theorist. Gradually, I moved to a more and more cognitive, representational position and did so for a straightforward reason: I kept stumbling into data sets that did not fit the associationist learning framework as well as they should (e.g., Trabasso, Deutsch, & Gelman, 1966). More and more I wanted to know both what young children could do and what they could not do. At the time, the field offered an unending list of tasks that preschoolers failed, including Piaget's conservation tasks. Regarding infants, it was commonplace to assume that newborns could not see or hear, let alone selectively attend to rather complex inputs. It was not easy for me to face the possibility that young children might have relatively abstract concepts in some areas. It was even more difficult to make the theoretical leap to the idea that some domains of cognitive development must be privileged, that is, that they benefit somehow from innate enabling learning structures. The ever-increasing body of evidence kept moving me in this direction.

Of course, to say that children have pockets of competence is not to say that they know everything. Nothing could be further from the truth. Even so, some researchers say that much too much is made of the evidence (e.g., Bogartz, 1996 a, 1996b; Cohen, 1998; Haith, 1998; Mix, Levine & Huttenlocher, 1997). Perhaps, but the issue is not whether the findings from some studies can be interpreted without appeal to an abstract level of analysis, but whether converging findings from a variety of studies make it reasonable to entertain the possibility that there is some real conceptual competence in young children. In this regard, it is critical also to keep in mind two facts. First, a particular expression of a biologically privileged structure need not show at birth. Second, all biological structures,--be they about concepts or not--- depend on the opportunity to interact with relevant inputs.

Evidence

Preschool Concepts

Traditional accounts. As indicated, most developmental theorists hold that infants gradually build up a notion of an individual object by associating the primitive sensations that are generated by different objects. Somehow, by forming associative clusters for similar objects, young learners eventually induce the notion of an object that is out there in a space and is independent of their sensations and actions. Now they can begin to associate perceptually similar objects and then induce concepts that cut across irrelevant perceptual attributes. To be sure, associations are not Piaget's fundamental building blocks of cognition: sensorimotor schemes are. Nevertheless, his infant must have repeated interactions with objects in order to achieve more coordinated memories between those sensorimotor schemes. Further, preschool-aged children rely heavily on the perceptual information in a given setting.

Some of Piaget's foundational assumptions about the nature of the data required to drive development also apply to the developmental theories advanced by Bruner (1964), Vygotsky (1962), and Werner (1940). In each case, learners are assumed to approach objects on the basis of simple motoric, sensory, or perceptual features. Given suitable opportunities to develop further knowledge of these features, the child is able to induce concepts that are more abstract. Initial concepts, whose cores are based on perceptual rules of organization are variously labeled as graphic collections, preconcepts, complexes, pseudoconcepts, and chain concepts.

Thus, whether the account of the origins of knowledge is rooted in an associationist or a classical theory of cognitive development, the assumption is that first-order sense data (e.g., sensations of colored light, sound, pressure, etc,. serve as the foundation upon which knowledge is developed. Principles that organize the build up of representations of concepts, as a function of experience and the opportunity to form associative networks or sensori-motor schemes, are induced. When children can form logical structures it becomes possible to have real, honest to goodness concepts, that is ones that meet the traditional view concepts: Concepts are defined by the intensional and extensional definitions. Put differently, they are made up of necessary and defining features. Since, all and only those exemplars that exhibit these features are extensions of the concept.

The belief that concepts are dependent on logical classification structures and their related combination rules has deeply ingrained in many scholars ideas about the nature of numerical concepts. From the developmental perspective, the theory is that, at first, children cannot even classify items with identical properties (e.g., Piaget, 1952; Vygotsky, 1962; Werner, 1940). Then, they begin grouping items that are perceptually identical – and then items that differ in a property but share a shape, and so on, until items that differ considerably with respect to their surface properties are treated as members of an abstract class: “things.” It is assumed that children must develop classification structures in order to classify at this level of abstraction. In the case of numbers, the abstract capacity to count is related to the idea that a given number (e.g., five) represents the set of all sets of that number, whether these are sets of five dogs, five ideas, five things in a room, or Lewis Carroll's miscellaneous collection of five kinds of things: shoes, ships, sealing wax. cabbages, and kings. Movement from the concrete to the abstract takes a very long time. Sir Bertrand Russell, who made fundamental contributions to the set-theoretical approach to number, remarked. "It must have required many ages to discover that a brace of pheasants and a couple of days were both instances of the number two" (Dantzig, 1967 p.6).

Next I address problems with the feature theories and their variants for concepts of living things and artifacts. Despite these difficulties with the traditional theory, some developmental lines of that continue to encourage consideration of stage-theoretical positions.

Lines of Traditional Evidence

Some of the best evidence in favor of stage theories and the traditional definition of concepts came from the various classification tasks that Bruner (1964), Piaget (1952), and Vygotsky (1962) used. Across a set of different tasks, preschool-aged children fail to apply a classification structure. That is, they do not use consistent criteria to sort a pile of objects, whether these are different colors or shapes, and they do not solve problems that require them to reason about the hierarchical relationships between superordinate and subordinate categories. For example, when Inhelder (1964) and Piaget asked children who were 7 years old or younger whether a bouquet of six roses and four tulips contained more roses or flowers, they invariably answered more roses.

Bruner (1964) presents the results, from two other tasks that add weight to the idea that young children cannot classify consistently (i.e., that they cannot use an intension to pick out all, and only those exemplars that are *extensions* of the concept. In these studies, children aged 6 to 19 years heard a series of concrete nouns and had to answer how each new item was both similar to and different from the already-heard items. For example, a child first heard "banana" and "peach" and then "potato." Then the child was asked how potato is different fro banana and peach and how it is similar. Children answered on the basis of perceptual attributes such as color and size and not categorical membership or even functional similarity. In a second task, the children were shown a large number of photographs and then were asked to select groups that were alike. Again, of the young children were based predominantly on shared perceptual attributes as opposed to share intentional criteria.

Using somewhat different procedures, Vygotsky (1962) reported a similar pattern in which younger children focus on common perceptual or thematic criteria. Given the robustness of the developmental classification data, it is easy to see why so many people believe preschool aged children have pseudoconcepts, pre-concepts, or idiosyncratic concepts that put together items that older children and adults would never put together. Indeed, it is an easy step from such results to a stage theory stating that older children and adults have the mental structures that support hierarchically organized concepts but that, toddlers, infants, and young children surely do not. This is especially so when we add in the many cases in which where younger children seem indeed to be perception-bound.

Preschool-aged children's persistent failure of the Piagetian conservation task is another salient example of their reliance on the surface-perceptual attributes of the displays. Piaget's (1930) work on early causal reasoning adds weight to the idea that preschoolers reason on the basis of the superficial appearance of things. For example young children seem to think that the sun and the moon move when (and because) the children themselves are moving. Flavell et al. (e.g., Flavell, Flavell, & Green, 1987) give us many examples in which 3-year-olds confuse appearance with reality, saying that a fake rock is "really, really" a rock, even though it is a sponge.

Preschool children need not be perception bound: As indicated at the beginning of this chapter, concepts do not stand alone. That is, a group of concepts is organized in such a way that it informs one's understanding of the individual concepts. Therefore, one might expect that the extent to which one has acquired abstract concepts would be related to how much one knows about the exemplars presented in a categorization task. Because many of the traditional classification tasks do not use items that researchers can be certain young children know about, one might ask what kinds of performances obtain when young children are presented materials that they do know about.

Gobbo and Chi (1986) followed up on the fact that some children are passionate consumers of information about dinosaurs, so much so that they become experts on the subject. This made it possible for the authors to provide a wonderfully compelling example of the role of young children's knowledge vis-a-vis their success on classification tasks. The more the children knew about dinosaurs, the more complex was the classification scheme reflected in their recall of the names of dinosaurs. They also could assign novel exemplars to the right category (e.g., meat-eating or not). Lavin, Gelman, and Galotti (2001) reported similar results in their study of what 5- and 6-year-olds know about the cartoon figures in a game called Pokeman that captured the attention of children around the world for several years.

There are about 150 different Pokeʹman characters appear in books, games, movies, television shows, and decks of cards that are sold, much as baseball cards are. The probability that any card will be in a deck varies, and this makes some cards more valuable than others. Somehow, children learn the monetary value of the different cards and often take this into account when trading cards, at clubs, schools, and in their neighborhoods. The different cartoon-like characters belong to social groups, teams, and "evolutionary groups."- in which one individual can advance to a physically more powerful character. It turns out that the young participants were much more likely to qualify as experts than were their parents. The experts had a great deal more to say about each of 20 cards, rarely mentioned perceptual attributes such as color or shape, and often referred to the non-obvious, conceptual facts: "This one's Ninetails, and he evolves from Vulpix. He's a fire Pokeʹman". Novices could not label as many items, preferred perceptual statements, or simply said that they knew nothing about the shown character.

These examples illustrate two important points. First, when young children are motivated to master much knowledge, they have conceptual organizational structures that are available for storing their knowledge in a coherent fashion. Second, when young children do master a body of knowledge, they do so in a way that relates the concepts in the domain to each other. Of interest is whether the previous examples are idiosyncratic and true for only for a limited number of children or whether there are domains of knowledge that many young children are inclined to learn about. The answer is that the latter is true. In the next section, I consider several examples that contrast with the persistence in some quarters of the view that young children are universally perception-bound, animistic, or egocentric. In the main, the latter two attributions follow from the first because young children's presumed reliance on perception is said to follow from their lack of the ability to form true or abstract concepts. Thus, young children are described as animists because they supposedly rely on the fact that animates move on their own. When other objects, such as the sun, the moon, a river, or machines appear to do the same, the idea is that young children cannot help but be animistic. Regarding egocentricism, the problem is that young children fail tasks that require them to take the perspective of others, perspectives they cannot see. Given that they have no data both the other person's perspective, they rely on what they can see, their own perspective. Hence, they end up looking egocentric.

Although there are many tasks in which children do appear to be perception-bound, animistic, and egocentric, there are also others in which young children use abstract knowledge, take the perspective of others into account and readily distinguish between animate and inanimate objects. Gelman and Baillargeon (1983) summarized a range of the latter studies. Subsequently, domain-specific theorists have uncovered large pockets of conceptual competence that are relevant to these demonstrations. Hence, the belief that very young children cannot help but be perception-bound is being eroded by the ever-growing body of evidence showing that they respond to complex information about the different kinds of causal conditions that go with animate and inanimate objects. These lines of research are joined with theoretical efforts to deal with the problems of the classical or traditional theory of concepts and concept development.

Alternative Theories of Concepts and Cognitive Development

Problems with Traditional Theories

The problems with the classical theory of concepts, as well as with variants of it, are reviewed in a number of sources (e.g., Fodor & Lepore, 1996; Medin, 1989). One serious problem relates to the question of what counts as a defining features. Although people say that dogs have 4 legs and fur, they cannot believe these defining features. Otherwise, they would say that a three-legged dog that lost its fur is no longer a dog. However, intuition (and research) show that this is not the case. Furthermore, features are context-dependent. The color purple can be thought of as a feature of wildflowers but not of dogs. That is, something about these concepts picks out purple as relevant in one case but not in the other. This amounts to saying, that given the concept wildflower, purple can be a feature. But then matters about the definition have become circular: Purple is a possible defining feature, only when the complex concept wildflower is already in place!

In an effort to deal with these problems, some theorist began characterizing concepts as prototypes (Rosch, Mervis, Gay, Boyes-Braem & Jonhson, 1976). According to this view, concepts have a central prototype. Extensions are included in the concept on the basis of the degree to which their features overlap with those of the prototype. Others suggested that the mind keeps track of both exemplars of a concept and the probability that it has the defining features. Different features then accrue different probabilities. Both theories are probabilistic in that each exemplar may or may not possess each of the defining features. Therefore, in the end they are variants of the classical theory of concepts. The move to a probabilistic solution appears able also to handle the fact that people think whales and turkeys are bad examples of fish and birds, respectively. However, probabilistic solutions run into trouble over the requirement that concepts be compositional. Consider the following well-known example: When people are asked to name a prototypical pet, they answer cat or dog. When asked to name a prototypical fish, they often say trout When asked to name a prototypical pet fish, they do not say dog-trout; instead, they say goldfish.

These problems led different theorists to several related moves. Medin (1989) and S. Gelman (e.g., 1996) adopted a version of the philosophical theory of essentialism. According to this position, surface similarities are no longer defining, and the role of individual features is deemphasized. Those features that are shared are due to a deeper, nonperceivable essence. The essences of natural kinds are internal and immutable, and transformations of surface features do not change these. Thus, a three-legged dog is still a dog because it continues to have its kind of essence. A person is still the same person even though he or she gains weight, gets a haircut, and has an artificial limb, again because the essence stays with the person through these changes. The fact that different people tend to share prototypical features is due to their related essences. The essences lead to causally related features that tend to co-occur, as in the case of feathers, wings, and beaks for bird. Put another way, the concepts are part of our innate conceptual heritage because our minds must acquire knowledge about the respective entities of nature. However, it is not necessary for us to know the way essences render causally related features. The idea is that the essence of a concept leads us to attend to and learn about the exemplars that form the extension.

Others theorists have made proposals that share with the essence position the idea that acquisition is guided by deep, unstatable principles at least as much, as by surface similarity. These include "first principles" (R. Gelman, 1990, 1998b); modes of construal (e.g., Dennett, 1987; Keil, 1995): core knowledge (Spelke, 2000); intuitive theories (e.g., Carey, 1985), and theory-theory (Gopnik & Meltzoff, 1997). These can be divided in terms of how much innate knowledge about the world humans are granted. Some theorists grant young learners innate domain-specific learning-enabling structures that are skeletal in form. Others grant infants something akin to theories, or at least content-rich core-knowledge structures.

R. Gelman (1990) chose to work with the notion of first-principles. Her idea is that different domain-specific principles constitute something like different mental-skeletal structures. Each set of first principles directs attention to as well as learning about those data in the world that are relevant to that, only that domain. This creates different domain-relevant learning paths, leading to the acquisition of knowledge that fills in the skeletal structure outlined by its first principles. Leslie (2000; Leslie & Scholl, 1999) articulated a very similar position in his account of why humans have a module. Gelman made her choice in part because of her belief that one does not want a theory of what is innate if that theory bears a remarkable resemblance to 17^{th}-century scientific thought. Keil developed a similar argument to explain his shift from a more content-rich theory of what is innate to that gives learners particular modes of construal. Gopnick and Meltzoff (1997), Spelke (1990; 2000) and Carey (1985;1999) adopted accounts that would seem to grant more specific knowledge or particular strategies for concept acquisitions.

Spelke's (1990) core knowledge principles for objects are also meant to support learning about objects in the world, but she notes that before people can do this, they have to find those bits of data that cohere together to constitute an object. However, because parts of many objects in the world are occluded, one must have a way to pick out those parts that bind together as an object. This is why Spelke's core principles for objects are as much about the world as they are about the human mind. She holds that it makes sense to endow the species with the kind of principles that will pick up the perceptual and conceptual data that identify objects that are"out-there".

Some might think that Carey's (1985; 1999P ideas about intuitive theories (and conceptual change) are a version of the theory-theory. This is unlikely. Her intuitive theories lack many standard characteristics of scientific theories. For example, individuals cannot state the principles that organize their knowledge. In addition, young children's generalizations about what they know about people and animals are often asymmetrical. Therefore, it is reasonable to paraphrase the word <u>theory</u> as something like "organized intuitive knowledge about X." Researchers could also follow the line taken by many who study early, untutored mathematical knowledge and refer to it as street arithmetic.

Gopnick's (Gopnick & Wellman, 1994; Gopnick & Meltzoff, 1997) position is quite different from those just covered. She and her collaborators hold that infants do not start out with domain-specific information-processing structures. Instead, they argue that young children are scientists in the making who use the methods and frameworks that scientists do. This sets the stage for children to build theories that are akin to those held by scientists. There is reason to ask whether the child-as-scientist metaphor is apt (Klahr, 2000). There is no question that young children actively engage their environment with lots of try-this-and-that, and they will stick with a problem until they achieve a solution (e.g., Karmiloff-Smith, &Inhelder 1974/75; Siegler,1996). Furthermore, the evidence supports the idea that even very young children are motivated to learn about causes. However, this is not the same as consciously thinking of specific hypotheses to test, reject, alter, and modify in the face of experimental data: nor does this guarantee that one will achieve understanding of a domain that is theoretical in the same way that scientists' hypotheses are theoretical.

At a minimum, the principles and entities of a scientific theory should be stateable, that is, rendered explicit. In their discussion of causal reasoning in preschool-aged children, Bullock, Gelman, and Baillargeon (1982) distinguished between using of implicit causal principles that support the ability to make predictions about the effects of varying components of a mechanism and then explaining their predictions. Young children predict the effect of a change in a mechanism very well even though they cannot explain the change vis-à-vis the nature of the mechanism. Never mind young children—probably very few adults know why pushing a button to turn on an air conditioner is effective, as studies of adults at first-ranked universities have shown (Wilson & Keil, 1998; Subrahmanyam & Gelman, in press).

Gopnick and Meltzoff justified their position on the grounds that theirs is a developmental theory. They asserted that theories that granting foundational core domains, modules, or principles are not developmental. This is a misunderstanding of how the term innate is used in the present era. It is not used to mean "preformed" and ready to spring forth full-blown from the head of Zeus as soon as the first relevant datum is encountered. In fact, all variants considered here are epigenetic learning theories, that is, theories that are meant to show how some innate structure can lead learners to identify data that will contribute to knowledge about the concepts that can become embedded in the skeletal structure of a given domain. The idea is that there are innate learning-enabling constraints or guidelines. For an extended treatment of this issue, the reader can consult Gelman and Williams (1998) and Chap. **TK** of Vol. 3 of this series

Some New Lines of Evidence

Animate and Other Worldy Objects

Leslie (1987) and Spelke, Phillips, & Woodward (1995) demonstrated that 7-month-olds know that although two inanimate objects must contact each other if a causal event that involves them is to occur, this is not so for two people. In Spelke et al.'s study infants watched two pairs of videotaped displays. The inanimate pairs of stimuli were two 5- and 6-ft tall objects that had distinctive novel shapes and contrasting bright colors and patterns; the objects moved toward each other, touched each other, and changed direction. The animate pairs were two people: A person holding her arms up and close to her body moved towards the other person and brushed against the other person. Infants looked reliably longer at the no-contact inanimate event; they showed no such preference in the animate event trials. Spelke's et al.'s findings are buttressed by Mandler and McDonough's (1996) finding that 9-month-old children organize their exploration of toys so as to keep examples of animals and vehicles in separate categories. Other studies converge on the conclusion that infants are sensitive to the different kinds of causal conditions that support the different movements and trajectories of animate and inanimate objects. (e.g. Gelman & Williams, 1998)

By the time children are about 3 -years old, they are well along in their understanding of the differences between animate and inanimate objects. Massey and Gelman (1988) showed that 3- and 4-year-old children are able to specify which novel objects depicted in photographs could move themselves both up and down a hill. The pictures were of objects drawn from five categories:

mammals, nonmammals, statues that share animal parts, wheeled devices, and rigid complex objects. The young children were extremely good at the task. Of critical significance is the fact that they did not rely on surface-perceptual similarity rule. For example, they denied the statues self-movement capacity even if these had arms and legs and their comments left no ambiguity on the matter, (e.g., "does not have real legs." "just a furniture-animal").

Studies in which young children are asked about the insides of objects can provide important evidence about whether they are limited to using the elementary sense data given by an object. What should happen when young children try to answer what is inside animate and inanimate objects? In neither case is there any reason to think that they can see the insides. If they are restricted to a perceptual level of processing, one possible solution would be to use a surface-appearance generalization rule. This would mean saying that the inside is like the outside (e.g., hard, red, etc.) The same rule should be invoked, no matter what category the object. If, however, young children possess implicit causal principles that distinguish between animates and inanimates (i.e., principles capturing the fact that animates move on their own and that inanimates need external sources of energy), then children should give qualitatively different answers for animates and inanimates. They do. When answering about animates, they say that a range of animals have blood, bones, and food on their insides; when answering about inanimates, they variously respond that there is nothing--stuff or material, the same color, dirt, and so on--on the outside. These findings are replicated in Subrahmanyam and Gelman (in press) and compliment findings from the laboratories of S. Gelman and Opfer (in press) and Simons and Keil (1995). For example, Wellman and S. Gelman (1997) found that preschool-aged children contend that a dog is no longer a dog if one takes its insides out. In contrast, a dog remains a dog if one takes off its outsides. Simons and Keil (1995) told 3-, 4-, and 5-year-olds about Freddy the alligator, who could see through the outside into the inside of things. The children were to help Freddy figure out which of two items had the “real” insides. For example, children saw line drawings of two sheep, each with an opening. One showed machine parts inside, and the other showed animal parts. The children’s choices made it clear that they knew that some things are more likely to be inside animals than machines and vice versa.

Young children’s ability to engage abstract or unseen criteria to classify and make inferences about different categories of objects does more than challenge the idea that they are restricted to a perception-bound state of mind. They highlight a key theoretical issue: What counts as relevant input? For example, how should researchers characterize the nature of the input that children took as relevant in the Massey and Gelman (1988) study? All the items were novel, and none moved. Bugs with shiny surfaces were treated as if they were animate, but statues with shiny surfaces were not. Details that were not present in the photographs (e.g., the feet of an echidna), were cited in explanations of why the creature could move up and down a hill. It must be that the children used some information in the photographs; the problem is to come up with a systematic account of how to characterize it. Massey and Gelman conjectured that it was that pattern of information one would use if one were concerned about causality. The idea is that principled concerns about cause of motion led to the selection of those kinds of information that are relevant to questions about causality. Just as adults might well ignore the color of a piano and focus instead on information about its weight, when deciding how to move it, so too children might focus on information about substance and ignore color when pondering whether a given item is capable of self-generated movement. From the child’s point of view, causal principles can provide the guidelines for finding and then learning about the pattern of inputs that are relevant to the animate-inanimate distinction.

It is a matter of fact that inanimate objects cannot cause themselves to move or change and that only animate objects have this ability. The reasons for this are straightforward. Depending on whether the object is animate or inanimate, the requisite energy for the initiation and maintenance of its movement comes from different sources. Accelerations of animate objects depend on the structured release of energy from biochemical reactions within these objects, which are made of biological material; in contrast, the source of energy for the accelerations of inanimate objects is external to the objects themselves. The cause of inanimate motion is an external force and there is always a transfer of energy from one object to another or a conversion of potential energy to kinetic energy (imparted energy). The cause of animate motions comes from the controlled and channeled breakdown of chemical bonds-the controlled release of internally stored energy. Animates act in ways that take into account their environment, be it animate or inanimate. This functionally adapted and readapted quality of animate motion is intimately tied to the fact that motion serves functions in animate beings. By contrast, motion serves no adaptive function for inanimate objects; such a consideration is simply not part of the discourse domain of physics.

This line of reasoning led Subrahmanyam and Gelman (in press) to ponder how young children would treat different kinds of machines, including those that are built to move. One possibility is that they would use an animist default strategy, that could be based on analogical reasoning (Goswami, 1995: Gentner 1983) about the seemingly shared capacity for self-generated motion. Subrahmanyam and Gelman did not favor this hypothesis because of their position that children yoke considerations about the causal source of motion to the kind of stuff of which an object is composed. Because machines fail the conjoint constraint, Subrahmanyam and Gelman thought it likely that children would place them in a separate category. The idea was that they would know that they did not fit either the animate or inanimate category. If the authors are right, then even very young children should not confuse machines with animate objects.

Because machines are man-made artifacts, knowledge of particular kinds of machines depends on opportunities to encounter and learn about them. Different machines mimic different animate properties. For example, when observed from the outside, vehicles seem to move on their own, and computers and robots can mimic the mental functions of human. Subrahmanyam and Gelman (in press) expected young children to say that some agent makes vehicles move. Because one needs knowledge of both the machine and the mental function to attribute animistic properties to computers and robots. Subrahmanyam and Gelman thought it likely that adults would be more animistic than young children. Put differently, although they did not expect young children to know a much about machines, they did not expect them to mix them up with clear cases of animates and simple artifacts. Our findings confirmed these predictions. The adults who were most inclined to say that robots could think and that computers could think and remember. Still, only rarely did they say that these objects breathe and have brains. This kind of selective animistic attributions led Subrahmanyam and Gelman to say that one needs to know a great deal to be an animist. It is a mode of thinking and explanation as opposed to a primitive structural stance. Parenthetically, metaphor, play, and religion are other modes of representation that humans can use. Thus, it is essential that researchers take care to ensure that their subjects understand which mode they are expected to engage.

The discussion about machines should make clear that a rational-constructivist position is every bit as concerned about acquisition mechanisms and input conditions as is any cognitive developmental theorist. Within the theory's frame of reference, innate and learned are not opposites. However, learning benefits from the presence of a skeletal set of principles, or organized expectations about different domains. A similar conclusion motivates an interesting line of cross-cultural research. Even though people all over the world might be concerned with the causal conditions that generate different kinds of objects, their knowledge and explanation systems of these need not be identical. In fact, one might expect people who live closer to nature than do those who live in high-rise apartment buildings in cities to have richer understandings of relevant biological dimensions of growth and reproduction. Studies by Atran (e.g., 1999) and Hatano and Inagaki (1999) provide such evidence.

Atran (1999) pointed out that biological taxonomies are probably universal, be they Itzaj Mayan, Japanese, or American. Although he does not endorse the idea that there are universal, native theories, he does point out that these taxonomies are "well-structured enough to impose constraints on any and all possible theories, thereby rendering biological theories possible" (p. 119). These structures encourage the search for causal explanations in the context of the environment in which one lives. This in turn can have tremendous influences on the kinds of explanations that members of a culture develop. For example, the Izaj live closer to their land and acquire considerably more knowledge about the ecological niches of the animals around them than do students at the University of Michigan students. Members of each group were asked to do diversity problems. The students were told that wolves and coyotes (similar animals) share one kind of disease because and that wolves and deer (less-similar animals) share another kind of disease. Then they were asked to say which disease was most likely to be common to all of the animals in a given locale. The students picked the wolf-deer disease because this pair spanned a more diverse set of animals. The Itzaj (who were asked about animals they knew) did not use the diversity strategy, as it turns out because they knew much more about the transmission of disease and the ecology of the animals. Whether they picked similar or dissimilar pairs of animals depended on how readily they could transmit a disease to other animals. Such findings led Atran to propose that intuitive theories of biology are more akin to intuitive theories of ecology. A similar line of reasoning is why Gelman (1991; Subrahmanyam and Gelman preferred to say that young children are inclined to develop schemes about the coordinated actions that animals and people share. Because animate actions take place in, depend on and respond to the surrounding environment, Atran's notion of ecological categories makes contact with this view.

Obviously, the differences explored by Atran (1999; Medin & Atran, 1999) and his colleagues are not due to innate difference in theoretical endowment but rather to the kinds of supporting environments for learning that cultures and their ecologies offer. Given ubiquitous and redundant experience with the particular set of data embedded in a cultural niche, the odds favor epigenesis of a theory that is sensitive to variables that bear on the skeletal structure of biological taxonomies. Hatano and Inagaki (1999) make a related argument and add developmental data. They gave young children living in a city in Japan the opportunity to raise goldfish. This led to an advance in their ability to attribute properties of animals to humans. Much work must still be done to sort out how innate guidelines foster movement onto various learning paths as well as how one should characterize supporting environments for learning. What is already clear, however, is that the rational-constructivist line of theorizing does not rule out learning. The search is for the kind of learning theory that goes with the assumption that cognitive development is facilitated by the innate contribution of first principles for some privileged domains. As it turns out, this is true even for a more abstract domain, number.

Numerical Reasoning

The literatures on early quantitative abilities adds weight to the view that very young children are inclined to learn about some specific domains with facility (Dehaene, 1997; R. Gelman & Williams, 1998). Converging lines of evidence can be marshaled in support of the view that principled understanding of addition and subtraction in combination with counting principles constitutes another core domain. The evidence comes from studies on preschoolers' abilities to detect principled counting errors, to invent counting strategies to solve addition and subtraction problems, to deal with novel counting problems, and to disambiguate ambiguous instructions and settings. Researchers have also studied cross-cultural commonalties in rates of learning the first nine digits in count lists, cross-cultural error patterns, animals' and infants' use of numerical information, and the fact that the input is extremely noisy, (Gelman, 2000; in press).

Infants develop expectations for the number of things or events that they are shown, including heterogeneous objects or drum beats, moving dots on a monitor, or events like a rabbit jumping (Starkey, Spelke, & Gelman, 1990; vanLoosbroek & Smitsman, 1990; Wynn, 1995). They look preferentially longer at a two-item or three-item heterogeneous visual display depending on whether they hear two or three drum beats (Starkey et al., 1990); they discriminate 8 from 16 dots (Xu & Spelke, 2000); they are surprised when the number of objects that they encounter changes as a result of unseen, surreptitious additions and subtractions (Wynn, 1992, 1995): and they discriminate displays that sequence ascending as opposed to descending numerosities (Brannon, 2001). There is debate about whether these results reflect use of a number-specific domain as opposed to a magnitude sensitivity or a one-for-one category-mapping rule. (e.g., Carey, 2000; T.J. Simom, Hespos, & Rochat, 1995). Even if this pattern of results does not represent the use of a nonverbal counting procedure to generate outputs that are added, subtracted, and ordered, the description of the primary data is still abstract and relational. Infants surely are not responding to bits of sensory input, punctate bits of light, color, and so on; otherwise, they would not habituate in experiments in which the items change on every trial, let alone discriminate displays with increasing values from displays with decreasing values.

Whatever the outcome on the debate about infants, there is considerable agreement that many children can use verbal counting procedures with understanding by some point in their third year. That is, their counting procedure is governed by the one-one, stable-order, and cardinal principles and can be applied to any collection of conceptually or physically discrete "things," in any order. The last tag used in the one-for-one assignment of ordered tags represents the cardinal value of a display. Counting is part of a number-specific domain because the representatives of numerosity (called numerons) generated by counting are operated on by mechanisms that are informed by, or are obedient to, arithmetic principles. For counting to provide the input for arithmetic reasoning, the principles governing counting must complement the principles governing arithmetic reasoning. For example, the counting principles must be such that sets assigned the same numeron are in fact numerically equal and the set assigned a greater numeron is more numerous than a set assigned a lesser numeron. The principles themselves need not be stated in terms of counting words or symbols. Any coordinate act that honors the counting-cum-arithmetic principles can be considered an example of counting. This is consistent with evidence that animals can count, and that preschool children with serious language impairments can do non-verbal arithmetic tasks (Arvedson, 1998) as well as the double dissociation between the ability to use complex sentence structure and numbers in a meaningful way (Grinstead, McSwann, Curtis & Gelman, 2001)

Brannon and Terrace (2000) showed that monkeys could order stimuli displaying as many as nine items. Once trained to arrange sets of one, two, three, and four items in ascending order, they spontaneously generalized to novel sets of items containing five to nine items. Platt and Johnson's (1971) study rats' ability to count is an especially nice example of nonverbal counting in animals. Their rats were required to press a lever an experimenter-determined number of times in order to arm a feeder. The target values of *N* varied from 4 to 24. The rats' responses were systematically related to the number of required presses per block of trials. As set size increased, so did the mean value of their presses. In addition, the variance for each value also increased proportionally to the mean. That is, the data from the study exhibited scalar variability.

Findings about animals' abilities to count are especially interesting. First, they challenge the belief that nonverbal creatures cannot have abstract concepts. Second, they encourage one to consider models of numerical representation that are not tied to set-theoretic and therefore traditional definitions of concepts. As long as the generative process honors the one-one, stable, and cardinal principles and tolerates a wide range of item types, one can say that it is a prospective counting device. A pulse generator and a computer are examples of such entities. It is not necessary to assume that a complex mediates the ability to count. Gallistel and Gelman (1992) favor a direct descendant of the Meck and Church (1983) accumulator model of animal counting data in their account of human nonverbal counting.. The model uses a discrete process to generate ordered quantitative representations, for both animals and humans. It is assumed that humans build bidirectional mappings between the quantities generated by the counting processes and the various count words and symbols that stand for a given cardinal value (Cordes, Gelman, Gallistel & Whalen, in press; Whalen, Gallistel, & Gelman, 1999). Evidence that humans relate different cardinal values to quantities comes from the well-known -set size and distance effects. When adults have to choose the greater of two digits, they are quicker to say which one is more, when the difference between them is greater or their values are smaller (Moyer & Landauer, 1967). Further, when adults do nonverbal counting, they also generate data that have the scalar variability signature (Cordes et al., in press; Whalen et al., 1999).

Of course, adults have two ways of representing cardinal values: one that is generated by a non-verbal counting procedure and one that is more mathematical. Even though they take longer to say $9 > 7$ than to say $3 > 1$, they still know that $9-7 = 3-1$. These different ways of dealing with numerals has been documented in a number of studies by Dehaene and his colleagues (e.g., Dehaene, 1997; Dehaene, Spelke, Pinel, Stanescu, & Tsvikin, 1999). There is even evidence that children can re-represent the words for natural numbers both ways. Huntley-Fenner and Cannon (2000) reported that discrimination success improves, as does the distance between two numerals. Zur and Gelman (2001) gave 4-year-olds a task that required them first to predict and then to check their answers for a series of arithmetic problems. The children's predictions were approximate but almost always in the right. Their counts were almost always correct.

Other lines of evidence indicate that there are some conditions under which even 2 1/2 year-olds relate addition and subtraction to cardinal values rendered by counting (see Gelman, 2000, for a review). However, how they accomplish this is open to different interpretations (Carey, in press; Huttenlocher, Jordan & Levine, 1994; Spelke, 2000).

R. Gelman and her colleagues (R. Gelman, 1993; R. Gelman and Cordes, in press; Gelman and Williams, 1998) favored an account that grants beginning speakers the nonverbal counting and arithmetic principles that constitute a number-specific domain. The finding of a common non-verbal counting mechanism that is shared by animals and adult humans lends some weight to such a continuity assumption. In addition, it provides beginning speakers a way of identifying and starting to learn the intended meaning of the counting list. The availability of a nonverbal arithmetic-counting structure facilitates the verbal counting system. This is because learning about novel data is aided whenever it can take advantage of an existing mental structure. The learner is more likely to select together those pieces of data that the culture offers as relevant. When the use rules of usage organizing the sequential sounds of a culture's particular count list honor the counting principles, they can be mapped to the available, implicit list. In this case, young learners have a way of identifying inputs that can be mapped to the counting principles, and the principles can then begin to render the lists numerically meaningful. Preverbal counting principles provide a conceptual framework for helping beginning language learners identify and render intelligible the individual tags that are part of a list that is initially meaningless. It also provides a structure within which they build an understanding of the words.

Of course, it is one thing to master the language rules that make it possible to generate successive numerals, forever. The issues of early variability are complex (R. Gelman, 1993; R. Gelman & Greeno, 1989). Here I focus on continuity and discontinuity. First, even adults, unlike computers, are less than enthusiastic about memorizing long lists of sounds that are not intrinsically organized. There is nothing about the sound "two", that predicts that the next sound will be "three," and nothing about the sound “three” that predicts that the next sound will be “four,” and so on. There is a non-mathematical, information-processing reason for expecting the task of committing even the first nine count words to take a considerable amount of time, and it does — as much as two to four years (Miller, Smith, Zhu, & Zhang, 1995). Because the nonverbal counting process requires the generation of a unique successor for each representation, the child must confront yet another serial learning problem This is the mastery of the structure of the base rules embedded in a particular language's counting system. The English count list lacks a transparent decade rule for at least the first 40 entries, and probably for the first 130 count words. Learning this rule takes a surprisingly long time. Hartnett (1991) found that a number of students in kindergarten and first grade had yet to catch on to the procedure for generating the count words in the hundreds, (Hartnett, 1991), most probably because many English speaking children think that *one hundred* is the next decade word after *ninety*. If so, in order for them to induce the 100s rule in English, they need to encounter relevant examples. Cross-cultural findings are consistent with this argument. Chinese has a more transparent base-10 count rule for generating subsequent count words, even for the 10s and decades. Although the rate at which English- and Chinese- speaking children learn the first nine count words is comparable, Chinese speaking children learn the subsequent entries at a much faster rate (Miller et al., 1995). Cultural variables also influence the extent to which count lists are used and extended. Given the introduction of trade as well as a language that has a generative count system, however, the uptake of an extended count list occurs rapidly (Crump, 1990; Gvozdanoviâc' ,1999; Zaslavsky, 1973).

A culture's rapid uptake of a count list that is better than one that is already in use is especially interesting. It represents an example of minds in search of the kind of list that best serves counting principles. It is as if the minds of people in these cultures are already prepared to adopt counting tools that will allow them to generate verbal counting successors. A related phenomenon was reported by Hartnett and Gelman (1998). They engaged children in kindergarten, first grade, and second grade in a thought experiment designed to encourage them to reach an explicit induction of the successor principle. To do this, they asked children to ponder a larger number, then add 1 to that, then add 1 again, and so on. Periodically, the children were asked if the number they were thinking about was the largest there could be or whether there were more numbers. Then, depending on the child's answer, they were asked what the biggest number was and whether they could add to it or what was the next number. A very large percentage of the children caught came to be able to state the successor principle.

It is important to recognize that the successor principle for natural numbers is consistent with the structure of the natural number knowledge that children bring to the task of learning about it. The operation of addition always increases a given number: that is, addition is closed for natural numbers. Indeed, this is why generative count rules are necessary. Learning is facilitated when there is structure mapping, but it is very likely that learning will be hard and even at risk when this is not so. For now, the learner has no existing structures, expectations, or models that can facilitate movement onto a relevant learning path. Instead, the learner must acquire both the database and structure of a domain. This is even a problem that one often faces in learning about new ideas that appear, at least from a cursory glance, to be related to already-learned domains.

Some Issues

From Core to Noncore Domains of Knowledge

The young child's competence with natural numbers does not guarantee clear sailing when it comes to learning numerical concepts that are not represented by a core domain. This is a problem for all theories of cognitive development. Movement from concrete to formal Operations, whether one is a school-aged child or a college-educated adult, does not assure a parallel passage to understandings of probability, rational numbers, mechanics, evolution, and chemistry, a startling fact given the Piagetian school's emphasis on these in the discussions of Formal Operations. The persistent problem that people all over the world have with the concept of a rational number, even with years of instruction, constitutes an especially serious challenge to associationist theories of concept learning. Despite a great deal of exposure to examples meant to foster the growth of associative strength for new concepts, there is little advance toward learning these with understanding.

In the end, new learnings in a domain will proceed rapidly when the structure of the target domain is consistent with that of the existing mental structure. However, if the structure of the target domain is different from that of existing knowledge structures, new learnings will be hard to come by. For learning with understanding to occur in a noncore domain, the mind must acquire both the structure and the domain-relevant data base of the novel domain. Learning in noncore domains can be handicapped for a straightforward reason: There is no domain-relevant structure, not even a skeletal one, to start the ball rolling. This means that the mental structures must be acquired de novo for non-core domains such as chess, sushi making, computer programming, literary criticism, and so on. In these cases, learners have a twofold task. They must acquire both domain-relevant structures and a coherent base of domain-relevant knowledge about the content of that domain (see also, Brown & Campione, 1990). It is far from easy to assemble truly new conceptual structures (see, for example, Carey, 1991; Chi, 1992; T.Kuhn, 1970) and takes a very long time. Something resembling formal instruction is usually required, and often this is not effective unless there is extended practice and effort on the part of the learner (Carey, 1985; 1991; Chase & Simon & Chase, 1973; Ericsson, Krampe, & Tesch-Romer, 1993). Efforts to provide domain-relevant instruction in noncore domains must recognize and overcome a crucial challenge: Learners may assimilate inputs to existing conceptual structures even when those inputs are intended to force accommodation and conceptual change (Slotta, Chi, & Joram, 1995; R. Gelman, 1993, 1994). That is, learners may fail to interpret novel inputs as intended and instead treat the data as further examples of the kinds of understanding that are available. As discussed later, the risk that this will happen is especially high in mathematics classes. Hartnett and Gelman (1998) illustrated this domain-based contrast between learning in core and noncore domains; by comparing and contrasting elementary school children's rapid-acquisition of the ability to express their understanding that every natural number has a successor with the painfully slow progress toward understanding of rational numbers -- so much so that many high school and college students around the world cannot be counted on to interpret rational numbers correctly.

The Role of Contingent Frequency in Concept Acquisition

There is mounting evidence that adults, children, and even infants automatically register the frequency of attributes, particular sequences of sound, kinds of objects, and so on (Hasher & Zacks, 1979; Gallistel, 1990; Marcus, Pinker, Ullman, Hollander, Rosen, & Xu, 1992; Saffran, Aslin, and Newport, 1996). For example, Hasher and Zacks (1979) showed children aged 5 to 8 years a series of pictures, in which each picture appeared zero to four times. Afterward, children in all age groups were highly and equally successful at reporting how many times a picture had been shown, even though they had not received any instructions to keep track of this information. I am sure that readers know whether white or green cars are more frequent and are very impressed with Marcario’s (1991) preschool-aged children who could play his “what will we take on a picnic” game—they were able to generate possible foods on the basis of a color cue. Infants are sensitive to the frequency of occurrence of different sound sequences in an artificial language (Saffran et al., 1996).

Some have taken these demonstrations to argue against a domain-specific account of concept acquisition and in favor of an empiricist one (e.g., Bates & Elman, 1996). There are two problems with this move. First, the fact that the mind registers contingent frequency is a problem for an empiricist theory. Within association theory, frequency is a condition for learning and serves to build associative strength; it is not specifically encoded and represented, nor does it feed a device that keeps a running total of frequency per se. Certain associations are stronger than others because they have had the benefit of more frequent encounters with particular pairings of stimuli, longer rewards, and/or rewards at shorter delays. That is, many different factors combine to determine associative strength, but the factors contributing to that strength, e.g., frequency, are not represented by associative strength and therefore are not recoverable as inputs for learning. Second, there is nothing about a domain-specific account that rules out the possibility that other structures use the output of its structure. From this point of view, the ability to keep track of domain-relevant frequency becomes a learning tool that results from the number domain. Thus, it can be recruited by various structures in the name of acquiring information about the kinds of structure-relevant cues that do and do not have predictive validity for that structure. In the case of language acquisition, studies with infants illustrate that the nature of a sound sequence, that is whether it is language relevant affects whether the frequency of its occurrence is learned. When it comes to learning about fruits, a frequency-computing device keeps track of the color of different exemplars. What is counted shifts again when the target learning task involves animals, machines, and so on.

Put differently, the structure of the target domain outlines the kinds of exemplars that become the input for an on-line, unconscious frequency tally. It is one thing to say that a cue has predictive validity and quite another to say that it is defining. Different motion paths and trajectories are more or less likely to be correlated with the movements of animate and inanimate objects. However, in most cases the motion paths are neither necessary nor sufficient (Gelman, Durgin, & Kaufman, 1995: Williams, 2000). To be sure, information that a given motion path has high predictive validity is useful information. It allows one to make a guess about a novel object or event. However, a guess is just that and therefore can be confirmed or disconfirmed. Should a huge, hard-surfaced mass that is in a garden start to move, the observer will undoubtedly no longer think it is a rock. Rocks simply cannot cause themselves to move–although turtles can, even if they are in an unexpected setting. Therefore, statistical information, by itself, does not serve to define concepts.

The Role of Features in Concepts

The previous discussion about frequency helps make sense of the data that are used to favor a prototype theory of concepts as well as the continued interest in various feature models of concepts. I hold that the frequency and prototype data are indicative of knowledge about particular relevant features as well as about their centrality (see Schwartz & Reisberg, 1991, for a relevant review). For example, wings are particularly relevant features of birds, and robins are more “central” exemplars of birds than are ostriches. From my point of view, these studies provide evidence that the frequency counter is at work as a mental learning tool. It is the reason why high-frequency features are more memorable, and why exemplars with many high-frequency features are judged better examples of a category. Interestingly, how such frequency information is used depends on the domain in question. Individuals will not say that an irregular verb that has a high frequency is a better example of verb than is a relatively novel example of one with a regular past tense (Marcus, 1996).

The proposal that a mental learning tool computes the contingent frequency of relevant encounters fits with conclusions drawn by other authors. Schwartz and Reisberg (1991, p. 391) suggested that researchers may need a three-part theory of concepts, in which “concepts are represented by a prototype, some set of specifically remembered cases, and some further abstract information,” where the parts all interact to accomplish correct similarity judgments and inferences. In this account, the recorded knowledge of frequencies and contingencies underlies subjects’ abilities to answer questions in ways that make them look like they learn prototypes and some salient domain-relevant exemplars. Keil (1995) has proposed that domain-general feature tabulation processes supplement “concepts in theories” structures. Armstrong, Gleitman, and Gleitman (1983) concluded that people know the difference between saying an object is an instance of a concept, and characterizing it as a good or bad instance. More generally, this account provides a way to reconcile these response patterns with the compelling arguments against the idea that people’s concepts are based on prototypes (Fodor & Lepore, 1996).

Further converging lines of thought exist with respect to children’s understanding of causality. Bullock, Gelman, and Baillargeon (1982) argued that causal principles lead children to search for causal mechanisms and assimilate causally relevant information about events, including the cue value of spatial and temporal cues. Ahn, Kalish, Medin, and Gelman (1995) concluded that information about covariation and causal mechanisms plays complementary roles in people’s decisions about causes. Cheng (1997) showed that people relate their computations of contingency to their beliefs in causal principles. A related thesis is presented in Koslowski’s treatment of scientific reasoning (1996).

Variability.

One cannot escape a deep truth about young children’s conceptual competence. Its display is almost always variable. There is both within- and across-task variability. Some might argue that this alone rules out any rationalist account of cognitive development or even that it favors an empiricist theory. These conclusions do not follow. Contrary to widespread assumption, such variability is equally consistent with and predicted by rationalist accounts of cognitive development. Because the form of the rationalist account offered earlier is a learning account, variation is expected, just as it is for any learning theory (R. Gelman, 1994, 2000; Gelman & Greeno, 1989; Gelman & Williams, 1998; Siegler, 1996). Researchers should consider the potential sources of variability more carefully, and examine how different theories account for these before choosing one acquisition theory over another. Variability could conceivably result from random noise in learning mechanisms, different learning solutions for the same underlying structure, different task demands, cultural differences in the interpretation of test settings, differences in the development of planning abilities, or a lack of achieved competence. A number of developmental variables have been proposed as candidates for systematic contributions to task difficulty. These include information processing load (Anderson, 1995; Halford, 1993) maturation of various brain structures (Johnson & Morton, 1991); knowledge (see above); skill at the conversation requirements of tasks (Siegal, 1996), and so on. One thing is certain. There is still much to learn about the nature of the variability. It is preferable to put the task this way as opposed to returning to all-or-none statements about early competence. Otherwise, one gives away the cumulative data base that researchers of early cognitive development have built.

Conclusion

This chapter started with an overview of different theories of cognitive development. As was shown, many of these share a commitment to the traditional and classical theory of concepts because they define concepts by appeal to a list of necessary and defining features and their use in classification structures. The problems with this approach were reviewed because they apply to theories of cognitive development and adult concepts. In both cases, it is extremely difficult, if not impossible, to identify a list of necessary and sufficient features. Nevertheless, theorists are reluctant to give up the classical theory. Recent developments in accounts of cognitive development offer a potential solution to the problem as well as an account of the role of features. This chapter identified a class of theories of cognitive development and learning was labeled rational constructivist. These all appeal to foundational, innate skeletal structures principles, or essences. They serve to outline domain-specific concepts in a way that tells learners what kinds of empirical inputs are relevant to their development. Different structures point to different classes of relevant inputs. The domains recruit a contingency computational device that keeps on-line, unconscious track of the frequency of different examples and of their relevant features. As such, the domain collects information about the relative frequency of different examples in the extension of the concept. This makes it possible to determine which features are prototypical. The persistent intuition that concepts and features are related is probably correct. However, features are not concept-defining–save perhaps for ad hoc “concepts.”

REFERENCES

Ahn, W., Gelman, S., A., Amsterlaw, J. A., Hohenstein, J., Kalish, C. W. (2000). Causal status effect in children's categorization. Cognition **76**, 335-343.

Ahn, W., (1998). Why are different features central for natural kinds and artifacts? The role of causal status in determining feature centrality. Cognition, 69, 135-178.

Ahn, W., Kalish, C. W., Medin, D. L., & Gelman, S. A. (1995). The role of covariation versus mechanism information in causal attribution. Cognition, 54, 299-352.

Anderson, J. R. (1995). Learning and memory: An integrated approach. New York: Wiley.

Armstrong, S. L., Gleitman, L. R., & Gleitman, H. (1983). What some concepts might not be. Cognition **13**, 263-308.

Arvedson, P. J. (1998). Numerical cognition in preschool children who have specific language impairment. Unpublished doctoral dissertation, University of California at Los Angeles.

Atran, S. (1998). Folk biology and the anthropology of science: Cognitive universals and cultural particulars. Behavioral & Brain Sciences **21**(4): 547-609.

Bates, E, & Elman, J.(1996). Learning rediscovered. Science, 274, 1849-1850.

Bogartz, R. S. (1996a). Measuring infant memory. Developmental Review **16**(3), 284-300.

Bogartz, R. S. (1996b). Measuring infant memory: Reply to commentary. Developmental Review **16**(3), 311-319.

Boyer, P. (1994). The naturalness of religious ideas. Berkeley, CA: Berkeley Press.

Brannon, E. M., & Terrace, H. S. (2000). The evolution and ontogeny of ordinal numerical ability. In A. Bekoff, C. Allen, & G.M. Burghardt (Eds.), The cognitive animal.

Brown, A. L., & Campione, J. C. (1990). Communities of learning and thinking, or a context by any other name. Human Development **21**: 108-126.

Bullock, M., Gelman, R., & Baillargeon. R.(1982). The development of causal reasoning. In W. J. Friedman (Ed.), The developmental psychology of time. New York: (pp. 209-253) Academic Press.

Carey, S. (1985). Conceptual change in childhood. Cambridge: MIT Press.

Carey, S. (1995). On the origins of causal understanding. In S. Sperber, D. Premack, & A. Premack (Eds.), Causal cognition: A multi-disciplinary debate (pp. 268-308). Cambridge: Oxford University Press.

Carey, S. (1999). Sources of conceptual change. In E. K. Scholnick, K. Nelson, S. A. Gelman, & P. H. Miller (Eds.), Conceptual development: Piaget’s legacy (pp. 293-326). Mahwah, NJ: Erlbaum.

Carey, S. (2000). The origins of concepts. Journal of Cognition & Development **1**(1), 37-41.

Chase, W.G. & Simon, H. A. (1973). Perception in chess. Cognitive Psychology. 4(1), 55-81

Cheng, P. W. (1997). From covariation to causation: A causal power theory. Psychological Review, 104,367-405.

Chi, M.T.H.(1992). Conceptual change within and across ontological categories: Examples from learning and discovery in science. In R. Giere (Ed.), Cognitive models of science: Minnesota studies in the philosophy of science. Minneapolis: University of Minnesota Press.

Chi, M. T. H., Glaser, R., & Farr, M. J. (Eds.) (1988). The nature of expertise. Hillsdale, NJ: Erlbaum.

Cohen, L. (1998). An information processing approach to infant perception and cognition. In G. Simion, & G. Butterworth. (1998). The development of sensory, motor and cognitive capacities in early infancy: From perception to cognition (pp. 277-300). Hove, England: Psychology Press.

Cole, M., & Cole, S. R. (2001). The development of children 4th ed.). New York: Worth.

Coley, J. D., Medin, D. L. & Atran, S. (1997). Does rank have its privilege? Inductive inferences within folk biological taxonomies. Cognition, 64, 73-112.

Cordes, S., Gelman, R., Gallistel, C. R., & Whalen, J. (in press). Variability signatures distinguish verbal from non-verbal counting—even in the small number range. Psychonomics Bulletin & Review

Crump, T. (1990). The anthropology of numbers. Cambridge, Cambridge University Press.

Dantzig, T. (1967). Number, the language of science. New York: Free Press.

Dehaene, S. (1997). The number sense: How the mind creates mathematics. New York: Oxford Press.

Dehaene, S., Spelke, E. S., Pinel, P., Stanescu, R., & Tsvikin, S. (1999). Sources of mathematical thinking: Behavioral and brain-imaging evidence. Science 284, 970-974.

Elman, J. Bates, E. Johnson, M. H., Karmiloff-Smith, A., Parisi, D., & Plunkett, (1996). Rethinking innateness: A connectionist perspective on cognitive development. Cambridge: MIT Press.

Ericsson, K. A., Krampe, R. T., & Tesch-Romer, C. (1993). The role of deliberate practice in the acquisition of expert performance. Psychological Review-100, 364-406.

Flavell, J. H., Flavell, E. R. & Green, F. L. (1987). Young children's knowledge about the apparent-real and pretend-real distinctions. Developmental Psychology **23**, 816-822.

Fodor, J. A., & Lepore E.(1996). The red herring and the pet fish: Why concepts still can't be prototypes. Cognition 58, 253-270.

Gallistel, C. R. (1990). The organization of learning. Cambridge: MIT Press.

Gallistel, C. R. & Gelman, R. (1992). Preverbal and verbal counting and computation. Cognition, **44**, 43-74.

Gelman, R. (1990). First principles organize attention to and learning about relevant data: Number and the animate-inanimate distinction as examples. Cognitive Science **14**(1), 79-106.

Gelman, R. (1993). A rational-constructivist account of early learning about numbers and objects. In D. Medin (Ed.,) Learning and motivation. New York: Academic Press 61-96.

Gelman, R. (1994). Constructivism and supporting environments. In D. Tirosh (Ed.), Implicit and explicit knowledge An educational approach. pp 293-322.

Gelman, R. (1998a). Domain specificity in cognitive development: Universals and nonuniversals. In E. M., Sabourin, & F. Craik (Eds.). Advances in psychological science: Vol. 2, Biological and cognitive aspects (pp. 557-579). Hove, England**:** 557-579.

Gelman, R. (1998b). Cognitive development. In H. S. Friedman, (Ed.), International encyclopedia of mental health,: Vol. 1, *(*pp. 489- 498). San Diego, CA: Academic Press.

Gelman, R. (in press). Animates and other worldly things. In N. Stein, P. Bauer, & M. .Rabinowitz (Eds), Representation, memory, and development: Essays in honor of Jean Mandler. Mahwah, NJ: Erlbaum.

Gelman, R. & Williams, E. (1998). Enabling constraints for cognitive development and learning: Domain specificity and epigenesis. In W. Damon (Series Ed.), D. Kuhn, & R Siegler (Eds.) Handbook of child psychology: Vol. 2. Cognition, perception and language (5th ed., pp. 575-630). New York: Wiley.

Gelman, R., & Greeno, J. G. (1989). On the nature of competence: Principles for understanding in a domain. In L. B. Resnick (Ed.), Knowing and learning: Essays in honor of Robert Glaser (pp.125-186). Hillsdale, NJ: Erlbaum**.**

Gelman, R., Durgin, F., & Kaufman, L. (1995). Distinguishing between animates and inanimates: Not by motion alone. In D. Sperber, D. Premack, & A. J. Premack (Eds.), Causal cognition: A multidisciplinary debate (pp. 150-184). Oxford: Cambridge University Press.

Gelman, S., & Opfer, J. A. (in press). Development of the animate-inanimate distinction. In U. Goswami (Ed.), Handbook of childhood cognitive development Oxford, England: Blackwell.

Gelman, S. A., & Wellman, H. M. (1991). Insides and essence: Early understandings of the non-obvious. Cognition, 38(3), 213-244.

Gelman, S. A. (1996). Concepts and theories. In R. Gelman & T. Au, (Eds.) Perceptual and cognitive development. (Vol. 3,pp. 117- 155). San Diego, Academic Press.

Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. Cognitive Science **7**, 155-170.

Gobbo, C., & Chi , M. (1986). How knowledge is structured and used by expert and novice children. Cognitive Development, **1**, 221-237.

Gopnick, A., & Meltzoff, A. N. (1997). Words, thoughts and theories. Cambridge, MIT Press.

Gopnik, A., & Wellman H. M. (1994). The theory theory. In S.A. G. Lawrence & A. Hirschfield (Eds.), Mapping the mind: Domain specificity in cognition and culture (pp. 257-293).

Goswani, U. (1995). Cognition in children. Hove, England: Psychology Press.

Greenfield, P. M. (1997). Culture as process: Empirical methods for cultural psychology. In J. W. Berry, Y. H. Poortinga, & J. Pandey (Eds.). Handbook of Cross-Cultural Psychology: Theory and Method. Boston: Bacon.

Grice, H. P., (1975). Logic and conversation. In P. C. Cole & J. C. Morgan (Eds.)Speech acts: Syntax and semantics. New York, Academic Press. **3**.

Grinstead, J., MacSwan, J., Curtiss, S, & Gelman, R. (under review). *The independence of language and number.*

Gvozdanoviäc´, J. (1999). Numeral types and changes worldwide. Berlin: Gruyter.

Haith, M. M. (1998). Who put the cog in infant cognition? Is rich interpretation too costly? Infant Behavior & Development **21**(2), 167-179.

Halford, G. S. (1993). Children's understanding, The development of mental models. Hillsdale, NJ:, Erlbaum.

Hartnett, P. M, & Gelman, R. (1998). Early understandings of numbers: Paths or barriers to the construction of new understandings? Learning and Instruction: The Journal of the European Association for Research in Learning and Instruction, **8**(4), 341-374.

Hasher, L., and Zacks,(1979). Automatic and effortful processes in memory." Journal of Experimental Psychology **108**(3), 356-388.

Hatano, G., & Inagaki, K. (1999). A developmental perspective on informal biology. In D. L. Medin, & S. Atran (Eds.), Folkbiology (pp. 321-354). Cambridge, MIT Press.

Hirschfeld, L. (1996). Race in the making. Cambridge, MA, MIT Press.

Huntley-Fenner, G. & Cannon, E.(2000) Preschoolers' Magnitude Comparisons are mediated by a preverbal magnitude mechanism. Psychological Science, II, 147-152.

Keil, F. C. & Lockhart , K. (1999). Getting a grip on reality. In E. Winograd & R. Fivush (Eds.), Ecological approaches to cognition: Essays in honor of Ulric Neisser. Emory symposia in cognition (pp. 171-192). Mahwah, NJ: Erlbaum.

Keil, F. C. (1995). The growth of causal understandings of natural kinds. In S. Sperber, D. Premack, & A. Premack (Eds.), Causal cognition: A multi-disciplinary debate (pp. 234-262). Cambridge: Oxford University Press.

Kitcher, P. (1982). The nature of mathematical knowledge. New York: Oxford University Press.

Klahr, D. (2000). Exploration science: The cognition and development of discovery processes. Cambridge: MIT Press.

Koslowski, B. (1996). The development of scientific reasoning. Cambridge, MIT Press.

Kuhn, D., Garcia-Mila, M., Zohar, A., & Andersen, C. (1995). Strategies of knowledge acquisition. Monographs of the Society for Research in Child Development **60**(4, Serial No. 241), 1-158.

Kuhn, T. S. (1970). The structure of scientific resolutions. Chicago: University of Chicago Press.

Lavin, B., Gelman, R., & Galotti, K. M. (2001, June). When children, not adults, are the experts: Explorations of the Pokeman phenomenon. Poster presented at the Annual Meeting of the American Psychological Association, Toronto, Canada.

Leslie, A. (1987). Pretense and representation: The origins of "theory of mind." Psychological Review, **94**, 412-426.

Mandler, J. M., & McDonough, L. (1996). Drinking and driving don't mix: Inductive generalization in infancy. Cognition **59**(307-335).

Marcus, G. F., Pinker, S., Ullman, M., Hollander, M., Rosen, T. J., & Xu, F. (1992). Overregularization in language acquisition. Monographs of the Society for

Research in Child Development, 57(4, Serial No. 228), 1-182

Marcus, G. F. (1996). Why do children say "breaked"? Current Directions in Psychological Science **5**(3), 81-85.

Marcus, G.F. (2001). The algebraic mind: Integrating connectionism and cognitive science. Cambridge: MIT Press.

Massey, C., & Gelman, R. (1988). Preschoolers decide whether pictured unfamiliar objects can move themselves. Developmental Psychology, 24, 307-317.

McClelland, J. L. (1995). A connectionist perspective on knowledge and development. In T. J. Simon & G. S. Halford (Eds.), Developing cognitive competence: New approaches to process modeling (pp. 157-204)> Hillsdale, NJ: Erlbaum.

Meck, W. H., Church, R. M. (1983). A mode control model of counting and timing processes. Journal of Experimental Psychology: Animal Behavior Processes. **9**, 320-334.

Medin, D. (1989). Concepts and conceptual structure. American Psychologist, 44, 1469-1481.

Medin, D. L., & Atran, S. (Ed.), (1999). Folkbiology. Cambridge: MIT Press.

Miller, K. F., Smith, D. M., Zhu, J., & Zhang, H. (1995). Origins of cross-national differences in mathematical competence: The role of number-naming systems. Psychological Science **1**, 56-60.

Mix, K. S., Levine, S. C., & Huttenlocher, J. (1997). Numerical abstraction in infants: Another look. Developmental Psychology, 33, 423-428.

Moyer, R. S., & Landauer T. K. (1967). Time required for judgments of numerical inequality. Nature 215, 1519-1520.

Piaget and Inhelder, B. (1958). The growth of logical thinking from childhood to adolescence. New York: Basic Books.

Piaget, J. (1930). The child's conception of physical causality. London: Routledge & Kegan Paul.

Piaget, J. (1952). The child's conception of number. London, Routledge and Kegan Paul.

Platt, J. R., & Johnson, D. M. (1971). Localization of position within a homogeneous behavior chain: Effects of error contingencies. Learning and Motivation 2: 386-414.

Premack, D., & Premack, A. J. (1995). Intention as psychological cause. In D. Sperber, D. Premack, & A. J. Premack (Eds.), Causal cognition: A multidisciplinary debate. (pp. 185-199). Oxford: Oxford University Press.

Rogoff, B., & Chavajay, P. (1995). What's become of research on the cultural basis of cognitive development? American Psychologist 50, 859-877.

Rogoff B. (2000). Culture and development. New York: Oxford University Press.

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. Science, 274, 1926-1928

Schwartz, B., & Reisberg, D. (1991). Learning and memory. New York: Norton.

Siegal, M. (1996). Conversation and cognition. In R. Gelman & T. Au (Eds.), Perceptual and cognitive development (pp.242-273). San Diego: Academic Press.

Siegal, M. (1991). Knowing children: Experiments in conversations and cognition. Hove, England: Erlbaum.

Siegler, R. S. (1991). Children's thinking. Englewood Cliffs, NJ: Prentice Hall.

Siegler, R. S. (1996). Emerging minds: The process of change in children's thinking. New York: Oxford University Press.

Simon, D. P., & H. A. Simon (1978). Individual differences in solving physics problems. In R. S. Siegler (Ed.), Children's thinking: What develops? Hillsdale, NJ: Erlbaum.

Simon, T. J., Hespos, S. J., & Rochat, P. (1995). Do infants understand simple arithmetic? A replication of Wynn (1992). Cognitive Development, 10, 253-269.

Simons, D. J., & Keil, F. C. (1995). An abstract to concrete shift in the development of biological thought: The "insides" story. Cognition, 56, 129-163.

Slotta, J. D., Chi, M. T. H., & Joram, E. (1995). Assessing students' misclassifications of physics concepts: An ontological basis for conceptual change. Cognition and Instruction, 13, 373-400.

Spelke, E. S. (2000). Core knowledge. American Psychologist 55(11): 1233-1243.

Spelke, E. S., Phillips, A. & Woodward, A. (1995). Infants' knowledge of object motion and human action. In D. Sperber, D. Premack, & A. J. Premack (Eds.), Causal cognition: A multidisciplinary debate. Symposia of the Fyssen Foundation (pp. 44-78). New York:, Oxford University Press.

Sperber, D. (1994). The modularity of thought and the epidemiology of representations. In L., A. Hirschfeld &, S. A. Gelman (Eds.), Mapping the mind: Domain specificity in cognition and culture. (pp. 39-67). New York: Cambridge University Press.

Starkey, P., Spelke, E. S., & Gelman, R. (1990). Numerical abstraction by human infants. Cognition, 36(2), 97-127.

Subrahmanyam, K., & Gelman, R.(with Lafosse, A.). (in press). Animate and other separably moveable things. In E. Fordes & G. Humphreys (Eds.), Category-specificity in brain and mind. London: Psychology Press

Trabasso, T., Deutsch, J. A. & Gelman, R. (1966). Attention in discrimination learning of young Children." Journal of Experimental Child Psychology **4**(291-299).

vanLoosbroek, E., & Smitsman, A. W. (1990). Visual perception of numerosity in infancy. Developmental Psychology, 26, 916-922.

Vygotsky, L. S. (1962). Thought and language. Cambridge, MIT Press.

Wellman, H. M. & Gelman, S. A. (1997). Knowledge acquisition and foundational domains. In W. Damon(Series Ed.), D. Kuhn, & R. Siegler (Vol. Eds.). Handbook of child psychology: Vol. 2. Cognition, perception, and language (5th ed., pp. 523-573). New York: Wiley.

Werner, H. (1940). Comparative psychology of mental development. New York: Harper.

Whalen, J. G., Gallistel, C. R., & Gelman, R. (1999). Non-verbal counting in humans: The psychophysics of number representation. Psychological Science 10**,** 130-137.

Williams, E., M. (2000). Causal reasoning by children and adults about the trajectory, context, and animacy of a moving object. Unpublished doctoral dissertation, University of California, Los Angeles.

Wynn, K. (1992). Addition and subtraction by human infants. Nature, 358, 749-750.

Wynn, K. (1995). Infants possess a system of numerical knowledge. Current Directions in Psychological Science, 4, 172-177.

Xu. F & Spelke, E. S., (1999). Large number discrimination in 6-month-old infants. Cognition, 74,1-11.

Zaslavsky, C. (1973). Africa counts. Boston: Prindle, Wever & Schmidt.

Zur, O. & Gelman, R. (2001, April). *Young children's understanding of the inverse relation between addition and subtraction.* Poster presented at the Bi-Annual Meeting of the Society for Research in Child Development, Minneapolis, MN.

.