

The Development of Folkbiology: A Cognitive Science Perspective on Children's Understanding of the Biological World

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Human beings are intellectually adventurous. We divide the world into kinds of things, such as living and nonliving, but we are also driven to go beyond categorization. We seek to understand and to explain. The understandings and explanations that we construct to make sense of the world can be thought of as *folk theories*. Folk theories are informal, often intuitive ways of explaining the *what* and the *why* of the world. Folk theories play a central organizing role in determining how children (or adults, for that matter) understand new facts (Gopnik & Wellman, 1994; Wellman & Gelman, 1998). We relate new information to old explanations; we understand it in terms of the theories or mental frameworks we already possess. For example, a child whose theory of the universe has the earth at its center and who believes in an absolute up and down (as opposed to a relative one) would likely explain night and day differently than we would and would probably make very different predictions about what would happen to a rock dropped into a hole dug through the earth.

One folk theory that has received attention in developmental psychology, anthropology, and the philosophy of science is *folkbiology*. Folkbiology refers to the cognitive processes by which people understand, classify, reason about, and explain the world of plants and animals. Our survival as a species has depended in large part on acquiring an intimate knowledge of plants and animals. At its core, research in folkbiology asks to what extent this dependence has shaped our basic conceptual apparatus. Do concepts like *plant*, *ferret*, and *rainbow trout* differ from concepts like *furniture*, *car*, and *ballpeen hammer*? Do we generalize about unfamiliar birds in the same way we generalize about

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unfamiliar lawn-mowers? Do we explain catching a cold in the same way we explain catching a baseball or catching our sleeve on a sharp edge? More generally, how is thinking about the living world like or unlike thinking about other domains of experience?

Folkbiology is not taught in schools; indeed, it often clashes with what we are formally taught in biology class. It does not involve the sanctioned means of gathering evidence and testing hypotheses that mark formal science. But that is not to say that folkbiology is a simple collection of facts and beliefs. It is more than that. It is a theory, and as with any theory, folkbiology is defined in terms of the phenomena it explains and the range of entities and causal processes it entails. Folkbiology provides predictions and supports explanations about such phenomena as growth, digestion, death, and illness—the phenomena of living things. If we eat too much, we gain weight. If deprived of air, we die. These are predictions we make on the basis of folkbiological understanding.

Recent research in the development of folkbiology has revolved around two related but separable issues. The first issue is to what extent and at what point in development folkbiological thought is truly distinct from thought in other domains. Do we have specialized conceptual tools for thinking about nature, or do we reason about plants and animals much as we reason about other aspects of experience? If we do possess these specialized tools, at what point in development do they emerge? To what extent, for example, are there early arising, perhaps even innately derived, dispositions to reason about particular biological entities and phenomena in particular ways? At what age ought we deem children's biological understanding sufficiently coherent to constitute a folk theory?

The second issue is the nature of developmental change in folkbiology. Does the organization of folkbiological knowledge undergo *quantitative* change as knowledge is acquired and initial principles are elaborated, or is it more a matter of *qualitative* change as one construal of the biological world is overthrown for another? Is the understanding of nature seen in the young child simply a less elaborate version of that seen in the adult, or do children and adults possess deeply different worldviews with respect to folkbiology, necessitating radical conceptual change at some point in development?

Thus, the study of folkbiology is central to the question of how children understand nature. But it also raises a number of other vital questions about the nature of thinking in general. In this chapter, we review empirical evidence on the development of children's folkbiological thought, using these two issues to guide our review. We then offer our own synthesis of a plausible model of development and highlight what questions remain outstanding in this domain of inquiry. Even the partial answers we come up with have important implications for science education as well as for public health and environmental awareness initiatives. They also tell us something about who we understand ourselves to be.

The Nature of Early Folkbiology

In this section we review evidence to date on what children know about living things, with an eye toward addressing the two questions raised above about the uniqueness of folkbiological thought and the nature of developmental change therein. We focus on areas central to any folk theory of biology: What kinds of things are alive, what is the place of humans in the natural world, what sorts of biological causality do children understand, and what are the unique properties of biological categories?

Animism

A crucial component of any biological understanding is the ability to differentiate living from nonliving things. By definition, biology is the idea that living things are different in important ways from nonliving things. One noted aspect of early reasoning about biology is the phenomenon of childhood animism, wherein young children report (and allegedly believe) that inanimate objects are alive, a trend that contrasts strikingly with adult notions and has led researchers to posit large, qualitative differences between the biological understandings of children and adults (e.g., Piaget, 1929; Carey, 1985). Piaget (1929) asked children which of a range of entities was alive. For example, "Is the sun alive? Is a dog alive? Is a flower alive?" He found that young children did not restrict their judgments of what is alive to the ontological category *living thing*

but also extended them to such inanimate objects as cars, clouds, and even statues. These findings were replicated more systematically by Laurendeau and Pinard (1962) and suggest that the basis for children's decisions about what is alive and therefore a legitimately biological object is very different from that used by adults.

However, more recent evidence suggests that early studies overestimated animistic reasoning. For example, Richards and Siegler (1984) systematically asked children ages four through 11 whether various objects (people, animals, plants, vehicles, other inanimate objects) that were described as either being still, being moved, or (where plausible) moving themselves were alive. Of interest was whether over the entire set of questions children's responses corresponded to systematic rules. Results showed that children rarely attributed life to vehicles and objects and never did so systematically. Most younger children systematically attributed life to people and animals, and by around age eight most children had added plants. Thus the largest developmental shift was not learning that inanimates are not alive but learning that plants are alive (see also Carey, 1985; Dolgin & Behrend, 1984; Richards, 1989).

Evidence also suggests cultural and experiential differences in patterns of life judgments. Hatano, Siegler, Richards, Inagaki, Stavy, and Wax (1993) present data showing that Japanese children may be more liberal than U.S. children in granting life status to objects such as mountains and that Israeli children are more conservative, often denying even that plants are alive. These findings are tied to specific beliefs in each culture. Recent evidence further suggests that urban, rural, and Native American children in the United States may differ in willingness to attribute life to plants. Ross, Medin, Coley & Atran (under review) find that all three of these groups are at ceiling, attributing life to an assortment of animals, ranging from bears to worms. However, Native American children are most likely to affirm that plants are alive. Rural children are less likely but show a developmental increase in the attribution of life to plants, and urban children tended neither to attribute life to plants nor to show such development.

Although they may not explicitly identify plants as living things, preschoolers may nevertheless understand important commonalities between plants and animals. For example, four-year-olds reliably report that plants and animals, but not human-made artifacts, can sponta-

neously heal or regrow injured parts (Backscheider, Shatz & Gelman, 1993). Four-year-olds also show a clear understanding of seeds and plant growth and of the underlying similarities between growth in plants and in animals (Hickling & Gelman, 1995). Inagaki and Hatano (1996) present evidence that five-year-olds projected biological properties such as growing and needing water to both plants and animals and coherently explained biological processes (taking in nutrients, growth, death) for plants by drawing on analogous properties for animals. Thus, the knowledge that plants are like animals and unlike nonliving things in important ways may be implicit in young children's reasoning.

In sum, contrary to classic Piagetian research, more recent and systematic investigations reveal little evidence of childhood animism. Most preschoolers systematically report that animals (whether mammals, fish, or bugs) are alive and that inanimate objects (whether bicycles or pencils) are not. Beliefs about the status of plants are less clear-cut. When asked directly, children are less consistent in reporting that plants are alive. However, children report that plants, like animals, grow, need water and air, and die, thereby acknowledging important biological commonalities between plants and animals. Finally, beliefs about the status of plants seem susceptible to cultural influences.

The finding that preschoolers do not consider plants to be alive suggests a qualitative difference between children and adults with respect to a core biological concept. Children might take behavior as their metric of living things and humans as the prototypical behaving (hence living) thing. However, when questioned more closely, preschoolers affirm that plants participate in the same basic biological processes as animals. Like adults, they appear to have carved out the domain of living things—including plants—as being united on the basis of important biological concepts. This early understanding may be frail and may not immediately be linked with the term *alive*, but it appears more compatible with a model espousing quantitative developmental change. Ideas of what is alive seem not to undergo radical revision with development.

Anthropocentrism

Carey (1985, 1995) has argued that children's early understanding of plants and animals is anthropocentric. In other words, children's understanding of other living things is largely in reference to, or by analogy

to, human beings (see also Inagaki & Hatano, 1991). Moreover, if young children see humans as the prototypical living thing, they should reason about other animals and plants on the basis of similarity to humans rather than on principles of biological necessity.

Several lines of evidence fit this characterization. Carey asked children which of a set of biological properties (such as breathes, eats, has bones, has babies) they believed could be attributed to a series of entities, ranging from humans to animals to plants to inanimate objects. For example, she asked, "Do dogs have baby dogs?" Results suggest that children attributed properties on the basis of similarity to humans (but see Coley, 1995). Analogous patterns were observed when children were taught a new fact about a given biological kind (for example, a dog "has an omentum") and asked whether other kinds (a bird, a fish, a plant) share that property. Carey (1985) reports a pattern of results consistent with the view that four- and six-year-old children's conceptions of the natural world are indeed anthropocentric. First, overall projections from humans were stronger than projections from other living things. Second, specific asymmetries in projection emerged, such that (for example) inferences from human to dog were stronger than from dog to human. Finally, children's reasoning followed striking violations of similarity, such that (for example) inferences from human to bug were stronger than from bee to bug. These patterns suggest that human is a privileged inferential base for the children Carey studied.

Carey (1985) interpreted her results from these and other tasks as indicating that young children's earliest reasoning about biological phenomena is not biological *per se*. She argues that these reasoning patterns reflect the operation of general—rather than specifically biological—reasoning mechanisms. Biological properties are attributed on the basis of comparison to a central exemplar—humans—rather than on the basis of membership in the class of living things, independent of similarity to humans. Preschoolers, according to Carey, lack knowledge of basic biological causal mechanisms and so have not yet constructed a naive theory of biology that can provide explanations and support predictions of phenomena. Rather, their understanding of living things centers around behavior and human beings as the prototypical behaving being. This pattern of reasoning has been interpreted as demonstrating that

young children possess an understanding of biological phenomena incommensurate with that of adults and that pervasive conceptual change is necessary for children to acquire the adult model in which humans are seen as one animal among many.

However, it is important to examine the generality of this anthropocentric pattern of reasoning on at least two grounds. First, rather than being diagnostic of deep conceptual commitments, this anthropocentric folkbiology may reflect a lack of knowledge about the biological world. Carey's subject population, in Cambridge, Massachusetts, may be relative folkbiological novices. Some evidence suggests that children who are more familiar with certain living kinds prefer to use knowledge of those kinds in reasoning. Inagaki (1990) showed that children who raised goldfish reasoned about a novel aquatic animal (a frog) by analogy to the goldfish, not to humans. So perhaps Carey's population (and that studied by most developmental researchers) did not have sufficient knowledge of nonhuman living kinds to use them as an inferential base. Increased knowledge might provide more salient biological exemplars that could in turn mitigate anthropocentrism.

Second, an anthropocentric folkbiology may reflect cultural assumptions about relations between humans and nature. Again, in the population studied by Carey, the differences between humans and nonhumans are very sharply drawn. Direct interaction with and dependence on nature is relatively rare. In urban, industrialized Western societies, humans are seen as existing apart from nature. In a culture where humans are perceived as an integral part of nature, people might be less likely to make anthropocentric construals.

In an ongoing comparative study of members of the Menominee Indian tribe of Wisconsin, Coley and his colleagues (Ross et al., under review) are currently addressing some of these questions. The Menominee are interesting for a number of reasons. First, according to the traditional Native American view, humans are an integral part of the natural world (Bierhorst, 1994; Suzuki & Knudtson, 1992). This contrasts sharply with the predominant Western view. Second, traditional folkbiological knowledge is especially salient to the Menominee. Unlike many woodland tribes, the Menominee reservation occupies (a small fraction of) their traditional range; thus, traditional knowledge of

local plant and animal species is still very relevant today. Moreover, the Menominee run a successful logging operation that employs traditional ecological knowledge to guide forest management. Finally, Menominee children differ from a typical urban or suburban sample in terms of both having a cultural tradition of viewing humans as an integral part of the natural world and having a great deal of experience with plants and animals. Children spend time fishing and hunting and in general have a high degree of contact with plants and animals. And indeed, contrary to results with middle-class urban children, Menominee children ages six and above show no evidence of anthropocentric folkbiological reasoning (Coley, Medin & James, 1999). A property projection task like that used by Carey revealed no evidence that *human* functions as a privileged inductive base, little evidence of asymmetries in projections, and no evidence for violations of similarity. Rather, Menominee children's projections were based largely on similarity among living things and to some extent on causal and ecological relations (see also Ross et al., under review). It appears that early folkbiology is neither universally nor inevitably anthropocentric.

In sum, most urban children have relatively little interactive experience with a range of living things and little cultural support to see humans as one living thing among many. For them, humans may initially provide a salient exemplar for biological reasoning. For populations with different levels of experience or cultural beliefs, this anthropocentric perspective appears to be strongly mitigated. Nor does attribution of life to animals seem based on comparison to a human exemplar. We currently lack information on the degree to which urban adults' folkbiology is anthropocentric and so cannot assess the degree to which children's views are discontinuous. But it would appear that anthropocentric folkbiology is not an inevitable step in development and that concentration on a single population (urban or suburban children from industrialized societies) may overemphasize discontinuity in development. More generally, these findings suggest that the very model of development within the domain of folkbiology may vary for different populations.

Biological Causality

As stated above, a central component of having a folk theory is having an understanding of the kinds of causes that unify facts falling under the

scope of that theory. Having a biological theory entails having an understanding of uniquely biological causal mechanisms. Do children have an understanding of the causal principles that govern biological change? To answer this question, researchers have examined preschoolers' understandings of specific phenomena such as inheritance, illness, and growth, with an eye toward how they organize facts to provide uniquely biological explanations and prediction.

Inheritance Biological inheritance has emerged as a central phenomenon in the debate over the development of domain-specific explanatory theories, for our adult understanding of it requires the interrelation of a system of concepts by means of core causal principles. At a common-sense level, an understanding of biological inheritance entails understanding and causally interrelating at least three concepts—that offspring tend to resemble their parents, that this resemblance pertains principally to intrinsic biological rather than acquired psychological traits, and that such resemblance is fixed by mechanisms eventually culminating in birth. Thus, if a daughter resembles her blonde mother because she has bleached her hair, we would not say that such a resemblance is an example of biological inheritance, nor would we say that a child's knowing, like his mother, where the cookie jar is hidden is an example of biological inheritance.

Researchers have shown that preschoolers know many, if not all, of the separate facts entailed in such an understanding. Recent studies have convincingly demonstrated that preschoolers understand that bodily traits and mental traits are different sorts of things and therefore that bodily traits lie outside of the explanatory purview of a naive theory of psychology (e.g., Inagaki & Hatano, 1993; Kalish, 1997). Preschoolers know, for example, that desiring and learning cannot directly alter bodily features as they can alter mental features; you cannot grow a third eye simply by thinking about it. Second, there is evidence that preschoolers understand that offspring will tend to resemble their parents: dogs tend to have puppies and not kittens; people with dark skin tend to have children with dark skin and not light skin (Gelman & Wellman, 1991; Hirschfeld, 1995; Johnson & Solomon, 1997; Springer & Keil, 1989). And third, many, if not most, preschoolers know that babies come from their mothers' bellies (Bernstein & Cowan, 1975; Springer, 1995).

Despite an impressive knowledge of these facts about inheritance, recent work suggests that many preschoolers make judgments that are not consistent with the commonsense understanding of inheritance outlined above. The question at hand is whether children conceptually interrelate these facts in terms of underlying biological causal mechanisms. In a series of recent studies (Hirschfeld, 1995; Johnson & Solomon, 1997; Solomon, 1996; Solomon, Johnson, Zaitchik & Carey, 1996; Springer, 1996; Weissman & Kalish, 1998), preschoolers were asked to judge whether adopted children would be more likely to resemble their birth parents or their adoptive parents on a range of traits. Most preschoolers did not show the adultlike pattern of judgment that children should resemble their birth parents on inborn physical traits and their adopted parents on acquired beliefs. Thus, although they know the facts of birth and distinguish mental from physical properties, most preschoolers appear to have difficulty coordinating this knowledge in a coherent fashion. Note, however, that when the task is simplified, a significant minority of preschoolers do perform as adults do. Moreover, many of those children who do not show an adultlike performance on the task still appear to think that the birth parent has special status in regard to parent-child resemblance, though they appear not to have completely worked out the implications of that relationship.

Thus, on the one hand, preschoolers' reasoning about the phenomenon of biological inheritance would appear to undermine the broad claim that they have an understanding of folkbiology consistent with that of adults and so has been claimed as support for a qualitative change model of the acquisition of folkbiology (Carey, 1995; Solomon et al. 1996). But on the other hand, some researchers argue that the simple undifferentiated bias of many preschoolers to regard birth parentage as special is itself an indication that children have the rudiments of a causal understanding of inheritance. They argue that such an association indicates that preschoolers understand there to be some implicit biological mechanism fixing parent-child resemblance, though their understanding of the phenomenon must undergo further refinement (e.g., Gelman & Hirschfeld, 1999; though see Solomon, 1996). These researchers take children's understanding of the phenomenon as support for the claim that folkbiology is a domain that undergoes quantitative change. Suffice

it to say that an understanding of biological inheritance consistent with that of Western biology is, at least to some extent, an acquired understanding and, for preschoolers, a fairly fragile one at that. Of course, even if it were shown that preschoolers do not reason about inheritance in terms of uniquely biological processes or that this birth-parent bias is not universal, this would not preclude preschoolers from reasoning in terms of biological causes about other phenomena. Indeed, because of the sophisticated interrelation of concepts that is required to understand it, biological inheritance may simply be an unlikely candidate for inclusion in preschoolers' early folkbiology. Preschoolers' folkbiology may not yet include all of the phenomena that adult folkbiology does.

Illness For adults, illness—like inheritance—is a biological process. Our adult folk theory of germ-based illness can be said to comprise three core concepts. Children must conceptualize the facts regarding contamination, contagion, and symptoms and interrelate them as adults do for a functioning theory of illness. For example, adults would attest that a person cannot catch a cold from another person by talking to him or her over the phone but could catch a cold by using a phone directly after it was used by a person with a cold.

There is evidence that preschoolers know many of the facts that we adults know to be relevant to a germ theory of illness. Certainly, preschoolers know that some things are bad for you. And they also know that there is such a thing as contamination and that contaminants may be invisible. For example, preschoolers will consider a beverage to be undesirable if it has had a cockroach or feces placed in it, even after the contaminant has been removed. And they will predict that drinking such contaminated beverages can make you ill (Rozin, Fallon & Augustini-Ziskind, 1985). Preschoolers also know the facts of contagion; they know that certain symptoms are contagious whereas others are not. They know, for example, that you can catch a cold but not a scraped knee from another person. And, as Kalish (1996a, 1996b) has demonstrated, preschoolers understand that contact with germs can make you ill.

Preschoolers may know most of the facts relevant to a germ theory of illness. They hear such commands as "Watch out, I don't want you to

catch my cough" and so learn that coughs are the sorts of things that can be caught; and they hear "Don't eat that, it has germs on it, and germs will make you sick." The question is whether children recruit these facts as part of an interrelated system of causal explanation. As adults, we understand that a cold is contagious but a scraped knee is not because of what we infer about how the symptom was acquired and what therefore underlies the symptom. We link our understandings that germs can cause colds to our understandings that colds can be contagious. But do preschoolers? It could simply be that preschoolers know that certain symptoms are contagious but never understand the relevance of the acquisition of the symptom by germs.

A recent study highlights this distinction. Solomon and Cassimatis (1999) designed a series of tasks to determine if children could link their knowledge of the acquisition of a symptom to its subsequent spread. Characters were described as having particular symptoms, such as runny noses or belly aches. In some conditions, the symptom was described as having been caused through contact with germs. For example, "A girl named Sandy breathed in some germs, and pretty soon she got a runny nose and had to stay home from school." In other versions, the cause of the symptom was attributed to a particular event involving an irritant. For example, "A girl named Sandy breathed in some pepper, and pretty soon she got a runny nose and had to stay home from school." The children were then asked whether they thought that the symptom could be caught by a friend who played with the ill child.

Adults, as is consistent with their having a germ theory of illness, judged the symptoms to be contagious if they were originally caused by germs but not contagious if they were caused by the irritant events. By contrast, not even half of the children under the age of 10 years made this distinction. Preschoolers, for example, judged the symptoms caused by germs to be contagious 84 percent of the time but also judged symptoms caused by events such as smoking to be contagious 72 percent of the time (the difference was not statistically significant). Preschoolers appear not to differentiate germs as contagious biological disease agents from nonbiological and therefore noncontagious symptom-causing agents such as poisons. In short, the preschoolers did not provide evidence that they understand germs to be a core explanatory concept in

their understanding of illness, one that brings their separate understandings of contamination, contagion, and symptoms into contact with one another.

Preschool children appear not to have an adultlike understanding of illness and contagion. Children do not interrelate contamination and contagion with differences between germs and poisons, nor do they identify germs as living things. How do we characterize this movement to an adultlike understanding in the context of a folkbiological theory? If differentiation of biological from nonbiological causal agents is considered central, then the movement to an adultlike germ theory might be considered qualitative change as children focus on what is properly deemed biological. However, these lines of evidence are not at odds with a quantitative model of folkbiological development at large. Perhaps children have a foundational understanding of contagion as a biological process in place early, and facts about germs are simply learned later in development and tacked onto this preexisting folkbiological theory of contagion. In other words, germs may be a fringe case of folkbiology, a detail rather than a central fact (see also Keil, Levin, Richman & Gutheil, 1999).

Growth and Natural Change Another central component of folkbiology is the idea that living things spontaneously grow and change, whereas other kinds of things do not. What do children know about growth and natural change? And more important, is there evidence that this knowledge is rendered coherent by a framework of causal principles?

Inagaki and Hatano (1996) present evidence that four- and five-year-olds believe that animals and plants, but not artifacts, spontaneously change over time. Rosengren, Gelman, Kalish, and McCormick (1991) showed that three- and four-year-olds understand that animals grow over time. This belief in the power of growth over time even led preschoolers to make nonnormative predictions; when presented with a picture of a small caterpillar and asked whether it would grow up to be a large caterpillar or a butterfly, children chose the former. They were not just reporting what they had observed but using beliefs about growth to make (in this case, incorrect) inferences.

While the extrapolation of size increases over time to nonnormative cases is a potent example of three-year-olds' understanding of biological growth, to truly possess an adultlike understanding of growth requires both the prediction that animals grow as a function of time and the prediction that artifacts do not grow as a function of time. Rosengren and his colleagues (1991) investigated this matter with interesting results. When three-year-olds were presented with an artifact and asked whether it would be the same size or larger after a period of time, they responded at chance levels. This would suggest that these children were unable to restrict their generalizations of growth to just animals. However, closer inspection of response patterns revealed order effects. When children were presented with animals before artifacts, they were more likely to apply the growth model to the artifacts. When artifacts were presented first, there was no evidence of carryover of a nongrowth model to animals. These results suggest that biological growth is an established model at three years of age but that its restriction to the biological domain is fragile.

Studies of children's understanding of growth and natural change favor a quantitative model of conceptual change. In these studies, preschoolers—like adults—report that animals and plants grow over time. Indeed, they overgeneralize this prediction to apply to species that undergo metamorphosis, a hallmark of theory-based reasoning. This understanding of growth seems fragilely biological; in some cases these predictions are restricted to living things and in some cases they are not.

Structure of Plant and Animal Categories

A major task facing the young child is to divide the world into discrete classes of things. By classifying objects, we can better understand them and make predictions about individuals that we have never seen before (Medin & Coley, 1998). There is evidence that children's categories of living things may have unique structural properties when compared to categories in other domains, such as inanimate objects (e.g., Gelman & Coley, 1991). Here we briefly touch on two ways in which children's living kinds may be structured differently from other concepts: children appear to assume that members of a living kind share an essence and

that category membership is a reliable guide for inferences about shared underlying properties.

Essentialism Psychological essentialism (Medin & Ortony, 1989) asserts that people act as if there is an underlying property that caused the observable characteristics of any item. It is this property (real or imagined), not observable characteristics, that ultimately determines category membership. For example, by age 10, children believe that a raccoon painted black with a white stripe and with a pouch of "smelly stuff" remains a raccoon despite its outward similarity to a typical skunk (Keil, 1989; see also Gelman, 2000, for a review of this evidence). This suggests that for 10-year-olds, something other than outward appearance makes an object a skunk. Two questions are of interest to the present discussion: at what age do children begin to show such essentialist reasoning tendencies, and are these reasoning patterns specific to folk-biological kinds, or do they reflect domain-general reasoning?

One consequence of essentialist beliefs is that superficial transformations should not change the identity of a living thing. Keil (1989) told kindergartners, second-graders, and fourth-graders stories about how animals or objects of one kind were altered to resemble animals or objects of another kind (for example, a raccoon was painted to resemble a skunk, or a coffeepot was made into a birdfeeder). When queried about artifacts, Keil found children of all ages believed that transformations changed identity. For natural kinds, there was a developmental progression: older children denied that transformations changed the identity of the object; a raccoon painted to look like a skunk was still a raccoon. Younger children rejected transformations that crossed ontological boundaries, judging that a porcupine, for example, cannot be turned into a cactus. In contrast, young children relied more on surface appearances to make decisions about category membership after other transformations, stating, for instance, that the painted raccoon was indeed a skunk. This suggests that although they may have some rudiments of an essentialist assumption in place, younger children would appear not to have the same biological understanding of the immutability and origins of species identity as do adults (see also Johnson & Solomon, 1997; Keil, 1994). In addition to having portions of the essentialist bias in place with

respect to plants and animals, by second grade children clearly differentiate between the results of transformations on kind membership for biological entities and artifact kinds. The children say that the same kind of superficial transformations that do not change category membership for plants and animals do change category membership for artifacts. This suggests that folkbiological kinds are subject to different causal laws than artifact kinds.

Another consequence of essentialism is the belief that a member of a kind has the innate potential to become like other members of the kind. Gelman and Wellman (1991), for example, have shown that preschoolers as young as four-year-olds believe that a baby animal would come to acquire the features characteristic of animals of its type whether or not it was raised with others of the same type, simply by virtue of being of its kind. Thus, a baby cow, raised by pigs, would come to moo and not oink because its essence is that of a cow, not of a pig. Even if planted with flowers, a seed from an apple would nevertheless grow into an apple tree. This is particularly remarkable because in the case of the seed there is no clear perceptual link between the seed and the adult plant, yet children believe that the origin of the seed, an apple, will determine what kind of plant it will eventually grow into. Even three-year-olds showed evidence that they discerned between the importance of insides and outsides in kind membership, for both animals and complex artifacts. Taken together, these results suggest that children have essentialist reasoning biases from early in development and that over time these biases become more pronounced for living kinds than for artifact categories.

Inductive Potential Related to the idea that members of the same category share deep underlying properties is the notion that categories guide inductive inferences. For instance, if asked to infer anything about *Bellin*, you would probably be at a loss. However, were I to mention that Bellin is a *cat*, you could then infer a great deal about him: he eats meat, meows, likes to be scratched between his ears, brings home dead mice, and so on. Thus, knowing the category membership of an object licenses inductive inferences about that object. One question that has arisen within folkbiology is whether living kind categories are particularly privileged with respect to inductive potential.

Experimental evidence clearly shows that children as young as two-year-olds assume that members of named kinds share underlying properties despite superficial dissimilarities (e.g., Gelman & Coley, 1990; Gelman & Markman, 1986, 1987). For example, Gelman and Markman (1986) showed young children pictures of two animals (such as a brontosaurus and a rhinoceros), gave category names to the animals (dinosaur and rhinoceros), and told them that each had a particular nonobvious property (cold-blooded or hot-blooded). The children were then shown a third animal (a triceratops) more superficially similar to the rhino but given the same category name as the brontosaurus. When asked which property it would be more likely to have, children made their inference on the basis of kind membership rather than superficial similarity. Despite looking like the rhino, the triceratops would share underlying properties with the other dinosaur. Numerous control studies show that inferences are based on shared category membership and not merely shared labels and that category membership guides inferences about intrinsic but not superficial properties.

These results show that very young children already assume that members of a named kind are likely to share novel features. Is this a general assumption about all categories, or is it limited to living kinds? Evidence to date supports the latter; there is some evidence that preschoolers are more willing to generalize within natural kind than artifact categories (Gelman & O'Reilly, 1988) and that by age eight children clearly and consistently show stronger inductions within natural kinds than artifact categories (Gelman, 1988; Gelman & O'Reilly, 1988). Note that this research has not explicitly examined generalizations within living kinds versus nonliving natural kinds (such as water and salt). Nevertheless, results suggest that an emerging component of folkbiological knowledge is the assumption that folkbiological categories are stronger than artifact categories as guides to inductive inference. In other words, by age two and a half categories reliably guide children's inductive inferences, and by age eight children, like adults, are more likely to bet that living kinds are alike with respect to novel underlying features than are other kinds of objects in the world.

However, children's category-based inductions do differ from those of adults. The similarity-coverage model of Osherson, Smith, Wilkie, López,

and Shafir (1990) predicts that an argument whose premises are more diverse will be judged stronger than an argument whose premises are similar. For example, one should be more willing to generalize to all birds from sparrows and flamingos than from sparrows and robins. Osherson et al. attributed this finding to *coverage*. Reasoners compare the taxonomic similarity of the premise categories (such as sparrows and flamingos) to sampled members of the more general conclusion category (kinds of birds). The premise set with better coverage—that is, higher taxonomic similarity to sampled instances—makes for the stronger argument. For the most part, undergraduate research subjects reason in accordance with this diversity principle, based on taxonomic similarity. However, developmental studies reveal that children through age 10 have difficulty grasping this phenomenon when reasoning about living things (Lopez, Gutheil, Gelman & Smith, 1992; Gutheil & Gelman, 1997; but see Heit & Hahn, 1999, for evidence that by age five children can successfully reason according to diversity when reasoning involves familiar properties).

Research in this area suggests similarities and differences between category-based induction for adults and children. Both show clear appreciation for the inductive potential of categories, but certain inductive phenomena seen among some adult populations (such as diversity-based reasoning) are hard to find among children. What is most at question is whether these characteristic induction patterns are particular to biological reasoning—perhaps tied to the discovery of higher-order biological categories (such as *mammal* or *living thing*)—or whether they represent a more general cognitive mechanism. Certainly nonliving kinds license inferences, so to some extent inductive potential must be a general cognitive mechanism. Is inductive potential especially strong in living kind categories? What scant evidence there is supports the case, but more research is needed. Current evidence does not suggest strong discontinuities in induction between children and adults and does not indicate whether induction over biological kinds is special.

How to Characterize Development of Folkbiology

Researchers in this field by and large agree on what children say when reasoning about plants and animals. What remains in dispute is what the

facts of early folkbiological reasoning imply about the underlying organization of knowledge and how that organization changes with development. At the beginning of the chapter we raised two related questions about the development of folkbiology. First, is the acquisition of folkbiological knowledge a relatively continuous process as knowledge is acquired and initial principles are elaborated, or is it a more discontinuous process as one construal of the biological world is overthrown for another? And second, do young children organize their knowledge of plants and animals differently from how they organize their knowledge about other kinds of objects?

We believe that evidence available to date supports a mixed model of development. Clearly, by the time they begin formal education, children use nature as a salient and distinct domain of inquiry as they try to construct an understanding of their world. Preschoolers appear to reason about the categories of plants and animals largely as adults do. Like adults, they assume that living kinds have essences and support induction. They do not differ systematically with respect to what kinds of things are considered alive. Thus, there seem to be important continuities between young children and adults in the way that folkbiological categories are structured and used in reasoning.

Does this mean that development does not occur? Absolutely not. As they grow and explore the world, children acquire vast amounts of information about plants and animals and about linking that information together in new ways. This knowledge impacts patterns of reasoning. Moreover, children appear to undergo important conceptual changes over the early school years regarding reasoning about biological causality. Evidence suggests that although children share many elements of adults' understandings of inheritance, illness, and growth, these elements are initially understood in isolation and are interrelated only in a causally coherent fashion over time. Causally coherent folkbiological principles may not be present early on but may emerge over development, suggesting discontinuities between children and adults in terms of biological explanation and therefore indicating the presence of genuine conceptual change.

The development of folkbiological thought involves both continuity and discontinuity. The way children form categories of plants and animals and the assumptions they make about the structure and

functions of those categories are much like adults. However, children differ markedly from adults in the way they understand biological causality and explain biological processes. What is less clear is whether folkbiological cognition is distinct from thinking in other domains. Part of the difficulty in resolving this issue lies in our current lack of knowledge in three areas.

Specifying the Adult Endstate

An important question that has been largely implicit throughout our discussion thus far is what adult theory of folkbiology children are acquiring. To what degree do adults possess detailed knowledge of biological causal mechanisms? It is difficult to characterize the process of development without a detailed look at the adult endstate (Coley, 2000). Adult biological knowledge may be much more fragmentary and incoherent than is often assumed (Au & Romo, 1999; Keil, Levin, Richman & Gutheil, 1999). It would seem unfair to hold children to a standard seldom met by adults in their culture. Ironically, a complete understanding of the nature of developmental change of those understandings may await more detailed evidence about adult folk understanding in this domain.

Reasoning in Different Domains

Another recurrent obstacle to our attempt to assess the uniqueness of folkbiological thought is the lack of evidence comparing reasoning about living things with reasoning about other kinds of things. We are accumulating a good deal of research about how children understand and reason about living things, but without detailed studies of comparable reasoning about nonliving things it is difficult to assess whether this understanding is properly thought of as folkbiological or whether it reflects more general conceptual mechanisms. A final answer on whether and when folkbiological thought is domain specific awaits such evidence.

Folkbiological Reasoning in Cross-Cultural Perspective

A final factor that has not been adequately explored is the differences in folkbiological theories and reasoning among different cultural groups.

Coley (2000) argues that both cultural beliefs about plants and animals and amount of practical experience with plants and animals could well lead to large differences in both the endpoint of development (what do most adults in the community know?) and the path by which development proceeds (direct teaching, apprenticeship, or guided participation). At the very least, Coley, Medin, and James's (1999) results cited above suggest that cultural beliefs may affect the rate of change in children's developing theories. Bloch, Solomon, and Carey (2001) found much the same thing in a cross-cultural study of reasoning about inheritance. But as discussed above, comparative results also suggest the possibility of even greater divergences. For example, it is possible that Menominee children younger than those studied would, unlike their older siblings, look just like similar-age majority-culture children, but it is also possible that they never do. It is not clear to what extent humans are understood to be integrated into the natural world. Would the Menominee children in the Keil task judge that an animal could be transformed into a human, thereby indicating that they did not recognize the ontological boundary between humans and other animals that is so intuitive to us? By extension, would they also be more apt than we to attribute higher thought to animals? Are the strong, almost theological, reactions that the attribution of higher thought to animals draws in the West particular to a time and a place? These are empirical questions, requiring cross-cultural research involving the interrelation of complex systems of reasoning about the psychological and biological worlds.

Conclusion

We began this chapter by introducing the idea of folk theories, arguing that to understand how we organize knowledge, we must understand how that knowledge is recruited to explain different aspects of our experience. Folk theories are commonsense, informal explanations of a set of related phenomena. We then used this idea to explore how children organize their knowledge of plants and animals, known as folkbiology, focusing on the nature of developmental change and the degree to which folkbiological thought is unique. We concluded that young children look much like adults with respect to the categorization of the world into

living versus nonliving things and with respect to how those categories inform inductive reasoning. In these areas, the acquisition of folkbiology seems to be a matter of quantitative change. However, children seem to undergo true conceptual change with respect to the coherent causal explanations they construct to explain biological phenomena like contagion and inheritance. It is less clear how unique folkbiological thought is, largely because the research remains to be done. More generally, by taking seriously the proposal that knowledge is organized in terms of folk theories, cognitive scientists studying the development of folkbiological thought have revealed both striking parallels in the way children and adults reason about nature and stark contrasts in the coherence of their folkbiological explanatory systems.

These recent advances in our understanding of the development of children's folkbiology have tremendous implications for science education. The implicit and explicit assumptions about the nature of cognitive development that underlie science curricula must take into account the notion that school-age children have the ability to contemplate nature with theoretical profundity. Leaving aside for now the academic debate over whether children's theories ought to be considered biological theories proper, cognitive scientists broadly agree that children bring to the classroom theories or interpretive frameworks that they use to make sense of the facts they encounter. When children's intuitive theories are consistent with the formal biology that is the target of classroom instruction, then children will be more likely to retain and integrate the key points of a class lesson. But their intuitive reasoning about biology is often not consonant with the target formal biology. For example, children's essentialist biases would appear to dispose them to understand that humans are qualitatively different kinds of beings than are other animal species. This bias to think in terms of discrete essences may well make it more difficult for children to grasp aspects of formal evolutionary theory. Of course, children's natural proclivity for theoretical reasoning also provides educators with the opportunity to engage them in explorations of the natural world at a far more profound and theoretically sophisticated level than had previously been thought possible. Just how these possibilities can best be realized is the subject of some very promising current research in the schools.

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