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MECHANICAL CAUSALITY IN CHILDREN'S "FOLKBIOLOGY"

Terry Kit-fong Au and Laura F. Romo

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MECHANICAL CAUSALITY IN CHILDREN'S "FOLKBIOLOGY"

I. DO CHILDREN HAVE FOLKBIOLOGY?

How do children explain and reason about biological phenomena? One idea that has set much of the research agenda for this topic since mid 1980's--put forth by Carey (1985, 1991)--is that young children use their knowledge about people to do the job. So, children may confuse biology with psychology, and they may think that all animate phenomena (e.g., growth, biological inheritance, life, death, illness) are governed by socio-psychological factors (e.g., motivations, feelings, beliefs, or attention to social forces such as morality and convention). For instance, preschool children talk about the origin of babies mostly in terms of the parents' intentional behavior such as going out to a store to buy a baby or making a baby and placing it in the mother's tummy (Bernstein & Cowan, 1975; Goldman & Goldman, 1982). Carey (1985, 1991) concluded from an extensive review of previous research that children do not seem to understand any uniquely biological causal mechanisms prior to age ten. Moreover, young children seem to use people as a prototype for reasoning about novel and nonobvious attributes of biological kinds (Carey, 1985). For example, preschool children often generalize a novel property such as "has a spleen" from people to other animals (e.g., dogs, birds, bees) primarily on the basis of how similar the other animals are to people. Such inductive inferences are quite sensible, even though not always correct. But interestingly, if the property is taught on dogs or bees, preschool children do not generalize it to people and other kinds of animals. Based on these and other kinds of evidence, Carey (1985, 1991) argued that a folkbiology might emerge from a folk psychology (or a folk theory of people), and children might not construct their first autonomous biology until age ten or so.

In response to this important and controversial proposal, considerable research efforts have been devoted to studying children's early knowledge about biological kinds. To date, there is rather compelling evidence that children begin to distinguish plants and animals from human artifacts by age three or four (e.g., Backscheider, Shatz, & Gelman, 1993; Hickling & Gelman, 1995; Keil, 1994); some children can apply their inchoate understanding of the biological-nonbiological distinction to novel entities (e.g., germs) as well as familiar ones by age five (Au & Romo, 1996; see also Keil, 1992). In other words, even before school age, children begin to sort out the ontologicial categories "biological kinds" and "nonbiological kinds" (see also Gelman, 1996; Wellman & Gelman, in press).

In addition to outlining the ontology in a domain, however, a framework theory should also specify basic causal devices in that domain in order to offer coherent bases for reasoning about relevant phenomena (e.g., Brewer & Samarapungavan, 1991; Wellman, 1990; Wellman & Gelman, 1992). To be credited with a folkbiology, then, children have to go beyond making an ontological distinction between biological and nonbiological kinds. They must also have some ideas about causal devices or mechanisms that apply only to biological phenomena. Given the importance of uniquely biological causal mechanisms in deciding whether a set of beliefs qualifies as a folkbiology, it is no coincidence that such mechanisms constitute a major battleground for the debate on when children construct their first autonomous biology.

II. DO CHILDREN KNOW ANY UNIQUELY BIOLOGICAL CAUSAL MECHANISMS?

Researchers including Hatano and Inagaki (1994), Keil (1992, 1994), and Springer (1995; Springer & Keil, 1991; Springer, Nguyen, Samaniego, 1996; Springer & Ruckel, 1992) have argued that, prior to age six or seven, children understand some causal principles in the domain of biological kinds. On the other hand, Carey (1985, 1991, 1995; Carey & Spelke, 1994), Atran (1994), and Solomon (Solomon & Cassimatis, 1995; Solomon, Johnson, Zaitchik, & Carey, 1996) have argued that children's early knowledge of biological kinds does not include explicit biological causal principles. But underneath all the arguments between these two camps lies a consensus (see also Au & Romo, 1996). Namely, most if not all participants of this debate seem to agree that, by age six or seven, children can understand some causal principles for explaining biological phenomena--now that Carey and her colleagues (1995; Carey & Spelke, 1994; Solomon et al., 1996) put the probable age onset at six or seven to accommodate recent evidence of early inchoate biological knowledge (e.g., Gelman, 1996; Hatano & Inagaki, in press; Inagaki & Hatano, 1993; Keil, 1992; Springer & Keil, 1991; Wellman & Gelman, in press).

We actually want to go against the tide by arguing that an understanding of any true biological causal mechanism is not something children pick up intuitively in everyday life. Even what Carey and her colleagues are willing to accept as evidence for such understanding--which we will review presently--is not about causal mechanisms per se. Rather, it is about causal input-output relations. Now is probably as good a time as any to explain the quotation marks around “folkbiology” in the title of this chapter: *Mechanical Causality in Children’s “Folkbiology.”* We chose this title because we are not convinced that children, or adults for that matter, spontaneously construct uniquely biological causal mechanisms from their everyday experience. No study that we know of has demonstrated that children or adults--without the benefit of science education--make use of such causal mechanisms to explain or reason about biological phenomena. So, if domain-specific causal devices constitute an integral part of any folk theory, then none of the folk conceptions about biological kinds documented to date seem to qualify as a folk theory (cf. Atran, 1994, 1995, in press). Where does this line of argument lead us? Not a very enviable spot, we must say. In some sense, we are questioning whether <u>folkbiology</u>--the very title of this edited volume--might be a contradiction in term. If neither children nor adults spontaneously construct uniquely biological causal mechanisms from everyday experience, can we really consider their folk conceptions about biological kinds to be folkbiologies? Because we are taking a rather precarious (if not indeed radical) position, we had better build our case carefully to make sure that our chapter will not be pulled from this collection of essays on folkbiology.

Much of the research on children’s understanding of biological phenomena has focused on biological processes, input-output relations, causal agents (e.g., vital force, essence, innards), and so forth, rather than causal devices or mechanisms per se. Because comprehensive reviews of this research literature already exist (Gelman, 1996; Hatano & Inagaki, in press; Wellman & Gelman, in press), we will try to be selective here.

Biological versus Psychological Processes

Children begin to distinguish <u>biological processes</u> from psychological ones by age four or five. They appreciate that some processes (e.g., growth, breathing) cannot be stopped by intention alone. For instance, people cannot prevent an animal from growing bigger and old, just because they want it to remain small and cute (Inagaki & Hatano, 1987). They also recognize that bodily processes such as running speed and psychological processes such as forgetfulness tend to be modified by different means--in these examples, by exercise and mental monitoring, respectively (Inagaki & Hatano, 1993). Moreover, 6-year-olds tend to attribute biological properties such as "has blood" and "sleeps" to predatory and domestic animals at the same rate, but they attribute psychological properties such as "can feel happy" and "can feel scared" more to domestic animals. By age eight, children use taxonomic groups (e.g., mammals, birds, reptile, fish) as a basis for attributing biological but not psychological properties. They use the predatory vs. domestic distinction to attribute psychological (e.g., "can feel pain," "is smart," "can feel scared") but not biological properties (Coley, 1995).

In several ecologically significant areas--growth, illness, kinship--children show rather impressive understanding from their preschool years on. For instance, preschool children know that "growth" and “self-healing” are unique to plants and animals (Carey, 1985; Rosengren, Gelman, Kalish, & McCormick, 1991; Backscheider, Shatz, & Gelman, 1993). From age six on, some children spontaneously attribute “can grow bigger” to novel entities such as germs (Au & Romo, 1996). Preschoolers also know about constraints on growth and development: Animals get bigger not smaller and become structurally more complex not simpler (e.g., from caterpillar to butterfly and not vice versa; Rosengren et al., 1991).

In the domain of illness, preschool children appreciate that illness and contamination can be caused by germs. Because germs are so tiny that they are not readily perceptible, children probably learn about germs primarily through language. Nonetheless, by age six, children manage to construct rather sophisticated beliefs about germs: Germs exist despite absence of perceptible evidence; germs can live, die, and grow bigger; germs can make people sick (e.g., Au & Romo, 1996; Au, Sidle, & Rollins, 1993; Kalish, 1996; Siegal, 1988; Rosen & Rozin, 1993).

Children's early knowledge of parent-child resemblance is equally impressive. For instance, preschool children expect that animals of the same family, more so than unrelated but similar looking animals, to share certain properties such as tiny bones, or an ability to see in the dark (Springer, 1992). They also expect that underlying essential nature is inherited and unaffected by upbringing. That is, a calf raised among pigs will grow up to moo and have a straight tail (Gelman & Wellman, 1991); a human baby shares racial characteristics with the biological parents rather than adoptive parents (Hirschfeld, 1994, in press). Whether children project novel, inherent characteristics from birth parents but not adoptive parents to birth/adoptive children remains an open question (e.g., Solomon et al., 1996; Springer, 1995). Nonetheless, children's inchoate understanding of parent-child resemblance seems to include some kind of causal input-output relations (i.e., input = some characteristics of the parents; output = similar characteristics in their baby). How the input is turned into the output--i.e., the causal mechanism--however, remains unspecified (Au & Romo, 1996; Carey, 1995).

To characterize children’s early knowledge about biological kinds, there are several proposals about underlying causal principles: vitalistic causality (Hatano & Inagaki, 1994; Inagaki & Hatano, 1993), functional-teleological explanations (Keil, 1992, 1994), essence (S. Gelman, Coley, & Gottfried, 1994), innards (e.g., R. Gelman, 1990). While each proposal has considerable empirical support, it remains unclear to what extent these proposed <u>causal agents</u>

are uniquely biological. How different is vital force from fuel in getting some machinery (human and otherwise) to work? How different is the role of function in driving the evolution of biological kinds and the evolution of technology and artifacts? How different is the essence for biological kinds from that for chemicals? How do innards differ for biological versus nonbiological kinds? Are these proposed causal agents different primarily in their domain of application (e.g., vital force for biological kinds and fuel for artifacts) but analogous in other ways (e.g., causal mechanisms for how they affect entities in their domain of application)? Perhaps, more importantly, none of the proposed causal principles offers any explicit causal mechanisms. What might the causal chain of events look like? How do the proposed causal agents such as "vital force," "function," "essence," or "innards" work? (see also Au, 1994; Au & Romo, 1996; Wellman & Gelman, in press).

DO ADULTS READILY CONSTRUCT UNIQUELY BIOLOGICAL CAUSAL MECHANISMS?

One way to study folkbiology is to explore children's beliefs about biological kinds and processes; another way is to study adults who have not received much or any science education. We have just begun to read about studies using the latter approach, so our knowledge in this area is bound to be patchy and limited. Our initial impression is that published reports of such studies tended to focus on causal agents and/or input-output causal relations rather than causal mechanisms. In the domain of illness, for instance, Nichter and Nichter (1994) reported that mothers in a rural area in the Philippines linked most respiratory conditions to sudden changes body temperature due to sun, rain, wind, bathing, and so on. A study of Latino adults' beliefs about <u>empacho</u> (roughly means "blocked digestion") revealed that it generally believed to be caused by "a bolus of food that sticks to the wall of the intestine, usually as a result of dietary indiscretion or swallowing a lot of saliva" (Weller, Pachter, Trotter, & Baer, 1993). Some African communities were reported to believe that diarrhea can be caused by: Teething, intestinal worms, eating bad food, drinking too much water, ingesting dirt, being touched by a father who has just committed adultery, worrying too much, being hit on the buttocks, and so forth (Green, Jurg, & Djedje, 1994; Yoder, 1995). See D'Andrade (1976) and Murdock (1980) for additional examples of studies focusing on causal agents and input-output causal relations rather than causal mechanisms.

It is perhaps no accident that people across cultures have rich beliefs about what might cause a person to have certain illness symptoms, what effect a treatment might have, and so forth. Such beliefs about input-output relations in the domain of illness—if roughly on the right track—can be very useful in illness prevention and treatment (see e.g., Berlin & Berlin, 1996). Beliefs about causal mechanisms of illness (or other biological phenomena for that matter), by contrast, seem more like a luxury than a necessity in everyday life. For example, the belief "smoking can cause lung cancer" could save lives if people act on this belief sensibly, with or without understanding any causal mechanism for how smoking might cause lung cancer. Lack of ecological significance, then, might be why causal mechanisms for biological phenomena are much less thought about in everyday life and much less documented in anthropological studies. Nonetheless, we did come across some published narratives revealing the informants' beliefs about causal mechanisms for specific illness.

GASTROINTESTINAL PROBLEMS

Consider this narrative collected in El Salvador:

> "In the stomach, food is cooked (*se cuecen los alimentos*) and therefore the stomach has to stay warm. When the climate turns cool, the stomach gets cold, letting food leave the stomach undigested. If you eat food with cold properties during the cold season you can also get stomach problems. Food which is considered cold, even though heated in the fire, always maintains this property. Tamales, beef or pork consommé and chicken soup are all considered cold food. In addition to these foods cucumbers and tomatoes are cool. The outside surface of the bean sticks in the stomach and for this reason it is not recommended to give children beans at nighttime, because the night is cold and the food is cold, thereby making the child sick" (Bonilla, Alferez de Castilo, & Piñeda, 1987; translated by and quoted in Kendall, 1990, pp. 183-184).

Temperature (i.e., hot, cold) and adhesiveness (e.g., the cold surface of bean sticking in the stomach) figure prominently in this account of causal chain of events that can lead to stomach problems. Note that temperature and adhesiveness are mechanical/physical rather than biochemical properties of substances. Similarly, naive mechanics also seems to be recruited by Latino adults to explain the symptoms of <u>empacho</u>. This illness is characterized by a cluster of symptoms including stomach aches and bloating, vomiting, cramps, diarrhea, constipation, and lack of appetite (Weller et al., 1993). As noted earlier, it is generally believed to be caused by a blockage of food in the stomach or intestines. For many Mexican-Americans, the recommended treatments include: Stomach massages, rolling an egg on the stomach, and popping the skin on the small of the back to dislodge the food blockage; drinking olive oil or herbal teas to loosen the food (Trotter, 1985). In this case, mechanical causal devices rather than uniquely biological causal devices are invoked when the informants tried to specify the causal chain of events that can lead to these symptoms and how the recommended treatments work to relieve the symptoms.

A third example of invoking mechanical causality in reasoning about treatment for gastrointestinal illness can be found among indigenous healers in Mozambique. When traditional African medicine fails to cure a child's diarrhea, indigenous healers consider "the child being without water" to be the cause of symptoms such as white eyes, edema in limbs, loss of appetite, loss of skin elasticity, general weakness, and thirst. The mechanical path of how water gets into the child is believed to matter a great deal. For instance, some healers noted that they can give a child water, but this will not do because the water will just swell up his stomach. Instead, "the child must be taken to a hospital quickly, where doctors 'will put water' (or 'blood') into the child by a needle in the arm" (p. 16, Green et al., 1994).

Breast Cancer

In a study of 26 African-American women in rural North Carolina with advanced breast cancer, 62% of these women seemed to believe that their cancerous lumps were triggered by a bump or blow to the body which causes some impurities in the blood to clump together in one place (Mathews, Lannin, & Mitchell, 1994). Here are some examples of how these women talked about the cause of their breast cancer (p. 793):

> May: " I noticed a knot in my breast in 1989, but it didn't hurt. It just came from bumping into the bed so I put it out of my mind."

> Jean: “I had a sore spot on my breast that came from bumping into the car door with my groceries. A lump came up there but it never bothered me.”
> Clara: “I had a pain in my arm for five years....I also had a knot in my breast all that time, but it would come and go....But then I noticed a few months ago that there was a big knot on my right breast where Mr. Jones (an Alzheimer’s patient she sits for) had been hitting me on the side. You know, if you get a hard enough blow, it makes some kind of blood clot, and if it stays there long enough it’s going to form something else.”
> Lucille: “That knot I had came and went. If you have dirty blood, the impurities have to go somewhere. And once I passed the change (i.e., menopause), that blood just stayed in me all the time. It was mounting up. When I fell down that day in the garden, they all came up to that bruise and they made a lump. That’s what made it so big.”

More generally, our glimpse of the medical anthropology literature suggests that while people can often come up with reasonable lists of causes, symptoms, and recommended treatments for various salient illnesses in their communities, their repertoire does not seem to include biological causal mechanisms for how specific causes can lead to specific symptoms or how specific treatments work. When they do manage to talk about causal mechanisms linking the causes and treatments to symptoms, they often fall back on their naive mechanics (e.g., temperature and stickiness of food, mechanical blows on the body). Even when they attribute an illness to moral transgression (e.g., a child’s diarrhea caused by the child’s father’s adultery) or negligence (e.g., a child’s diarrhea caused by the child’s mother stepping into milk expressed from a woman who has had a miscarriage), mechanic transfer of contaminants or impurities is often implicated (e.g., the adulterous father touching the child; the careless mother nursing the child). When mechanical causality is not recruited to fill in specific causal chains of events for natural or supernatural causation of illness, typically little else is offered in terms of explicit causal mechanisms (see e.g., Murdock, 1980).

MECHANICAL CAUSALITY IN CHILDREN’S “FOLKBIOLOGY”

To date, only a few studies have explicitly examined children’s beliefs about causal mechanisms for biological phenomena. In one study, Inagaki and Hatano (1993) compared children's preference for intentional, vitalistic, and mechanical causal explanations for biological phenomena. They asked children, for instance, why we eat food everyday. Children were asked to choose among three explanations: "Because we want to eat tasty food" (intentional); "Because our stomach takes in vital power from the food" (vitalistic); "Because we take the food into our body after its form is changed in the stomach and bowels" (mechanical). Likewise, when asked why we take in air, children were asked to choose from: "Because we want to feel good" (intentional); "Because our chest takes in vital power from the air" (vitalistic); "Because the lungs take in oxygen and change it into useless carbon dioxide" (mechanical). In this study, 6-year-olds chose vitalistic explanations as most plausible most often (54% of the time). Eight-year-olds chose vitalistic explanations only 34% of the time; they generally preferred mechanical explanations (62%). Adults overwhelmingly preferred mechanical explanations (96%).

Springer and Keil (1991) also found that 6- and 7-year-olds favored mechanical causality over other kinds of causal mechanisms (e.g., genetic, intentional) in explaining why, for instance, how a baby flower may get its blue color or how a puppy may get its brown fur color. Children in this study were offered three kinds of possible explanations: Intentional, mechanical, and genetic. One example: "The mother flower wanted her baby to be blue just like her. Because she wanted the baby to be blue, she gave it some very tiny things that went into the seed and turned the baby flower blue" (intentional); "Some very tiny blue pieces went from the mother to the baby flower. These tiny blue pieces went into the seed and got all over the baby flower. Because they got into the baby flower's petals, the baby flower turned blue" (mechanical); "Some very tiny colorless things went from the mother to the baby flower. These tiny things put the blue color together in the baby flower. Even though these tiny things aren't any color, they could make the baby flower blue" (genetic). The mechanical account (or what Springer and Keil called the "gemmulic account") was judged best by the 6-year-olds nearly 80% of the time. An important difference between the winner and the losers is that the mechanical account specifies a simple mechanical transfer of color pigment, whereas the genetic and the intentional accounts did not.

Together, these studies suggest that mechanical causality is the mechanism of choice during middle childhood for explaining biological phenomena. Our quick survey of medical anthropological studies also hints at adults' reliance on mechanical causality when pressed to speculate on specific chains of causal events inside the human body--if scientific accounts are not in the adults' repertoire. One caveat: In Inagaki and Hatano's (1993) and Springer and Keil's (1991) studies, children were asked to choose among several possible mechanisms, rather than to generate one on their own. As Carey (1995) pointed out, it is very difficult to make different explanation types comparable with respect to the informativeness of the explanation and familiarity with the information it contains. So, when children chose one type of explanation over another, it is not always clear why they did so.

Nonetheless, we suspect that mechanical causality is the mechanism of choice for children and adults--especially those without the benefit of science education--in their attempts to make sense of biological phenomena. For one thing, from infancy on, children know and rapidly learn quite a lot about how objects and substances behave in terms of mechanics. Their naive mechanics allows them to appreciate that physical entities will move according to principles such as cohesion, solidity, contact, and continuity (e.g., Carey & Spelke, 1994; Spelke & Hermer, 1996; Wellman & Gelman, 1992, in press). Although children and even adults make erroneous predictions about the dynamics of more complex systems (e.g., wheels and pulleys), they are generally quite good at reasoning about whether an object or a portion of substance will stay put or be set in motion, how it will move (as long as the entity can be thought of as a single particle of mass), and so forth (e.g., McCloskey, 1983; Proffitt, Kaiser, & Whelan, 1990). So, before children and adults understand any uniquely biological mechanisms, it makes sense for them to apply their naive mechanics--a rather well worked-out foundational theory--to reason about living things as well as nonliving things. Indeed, as discussed earlier, adults from different cultures seem to recruit their naive mechanics to explain causal links between causes, symptoms, and treatments of illness.

Psychological Causality: Another Contender

Another obvious source for causal mechanisms at children's disposal, as Carey (1985, 1991, 1995) pointed out, is naive psychology. But by age six or so, as discussed earlier, children can grasp the conceptual distinction between biological and nonbiological kinds and that between biological and psychological processes. They recognize that bodily processes and psychological processes tend to be modified by different means. From that point on, it is unlikely that children confuse folkbiology with folk psychology. So, when they offer a socio-psychological explanation for a biological phenomenon (e.g., John has a cold today because yesterday he played with Mary, who kept coughing and sneezing while playing with him), it does not necessarily mean that psychological causality is the only game in town. At a different level of analysis, children could be thinking about Mary passing some of her cold germs to John when she accidentally sneezed or coughed at him. In other words, children’s use of socio-psychological explanations for biological phenomena cannot by itself be taken as prima facie evidence for children confusing folk psychology with folkbiology.

What about children under age six? If children have to stretch either their naive psychology or naive mechanics to reason about biological processes, it seems plausible that they would opt for naive mechanics. For one thing, even preschoolers can distinguish mental and physical entities (e.g., a cookie in a dream vs. a cookie in real life) and processes (e.g., thinking about eating a cookie vs. actually eating a cookie; Wellman, 1990; Wellman & Estes, 1986). Note that, like mechanical processes, most biological processes (e.g., growth, healing, reproduction) act on physical rather than metaphysical matter. By contrast, psychological processes typically affect thoughts, feelings, and at times behaviors. So, before children understand any causal mechanisms that are uniquely biological, it seems more natural for them to stretch their naive mechanics rather than naive psychology to explain biological phenomena.

In Children’s Own Words

Earlier, we have offered some suggestive evidence that, without the benefit of science education, adults in different cultures invoke mechanical causality to explain the causes, symptoms, and treatments of illness. Inagaki and Hatano’s (1993) and Springer and Keil’s (1991) studies also suggest that mechanical causality is the mechanism of choice during middle childhood for explaining biological phenomena. But children in these two studies did not have to generate their own explanations; they were asked to choose among several possible mechanisms. Given the methodological concern raised by Carey (1995), namely the comparability of different explanations types for extraneous factors, it would be helpful to hear what kinds of explanations children can come up with on their own.

A Case Study

Reproduction. We have been following one child’s quest for biological knowledge for some time. The first report was filed in 1996 (by Au and Romo, p. 210):

> A child we know asked, at age 2 years 9 months, where she was when her mother planted the orange tree in their backyard and was told that she was in her mother's tummy. She then wanted to know where she was when her mother planted the lemon tree in their front yard. The mother said, "You weren't even in my tummy yet." The child was visibly upset about her non-existence once upon a time. The mother relented and explained, "Half of you was in my tummy; the other half, in Daddy's tummy." The child went away happy but came back in a few minutes to ask, "Were my feet in Daddy's tummy?" The mother was determined to help the child supplant this mechanical explanation with a proper one, namely, a biological one. She explained that the two halves did not have arms and legs; instead each half was like

> a little egg (without the shell, she emphasized); the two little eggs mixed together and then grew into a baby. The toddler nodded and talked about this matter-of-factly a few times in the ensuing weeks. Her mother was pleased with the progress until the child asked one day, "How did I get into your tummy? Did Dr. Wilkinson cut open your tummy to put me inside?"

The notion of procreation is difficult to grasp. How can the concept of object permanence--at the core of naive mechanics--be reconciled with the transition from nonexistence to existence in reproduction of biological kinds? This child in this case went with her intuitions about mechanical causality. Understanding such a transition can be difficult even for adults. Just think about how intellectually unsatisfying the notion of "spontaneous generation" is for explaining generation of bacteria and fungi from apparently nothing. One could almost imagine the scientific community's collective sigh of relief in 1862 when Pasteur finally managed to show experimentally that micro-organisms came only from other micro-organisms; that a completely sterile solution will remain so unless contaminated by some micro-organisms (e.g., Pruves, Orians, & Heller, 1992). Consider also the Biblical account for the origin of the human species. To create Adam, God took some dust from the ground and shaped it into a human figure. To effect the nonbiological to biological transformation, God then breathed into it life and created a man. To create Eve, a rib was taken from Adam and transformed into a woman. In this account, biological beings were created by transforming physical matter (i.e., dust, air in a breath, rib bone) rather than by spontaneous generation of some sort. These two events--one in the history of science and the other in religion--are so different and yet so alike. They both illustrate people's tenacious hold onto their naive mechanics and their reluctance to cross the ontological boundary of physical and metaphysical matter in tracing the history of an individual entity.

Illness. We revisited the child a few days after she had celebrated her fourth birthday. By then, according to diary records kept by the mother of the child's speech, this 4-year-old seemed to know quite a lot about germs, infections, and relevant treatments. For instance, she often talked about good germs that can be used for making yogurt and bread, and bad germs that can get into people's bodies to make them sick. She knew that germs need nutrients in order to multiply (by splitting themselves into baby germs). She knew that soap can help wash germs off people's hands and bodies; that brushing one's teeth with toothpaste can help wash germs off the teeth. She knew that there are different kinds of bad germs. For instance, at age 3 years 9 months, her mother explained to her that the Los Angeles Zoo decided to give up its penguin exhibit and moved it to another zoo because the penguins kept getting sick, perhaps because Los Angeles is too warm for penguins. The child asked, "Is it because the germs that make penguins sick are different from the germs that make people sick?" The mother asked, "Why do you think so?" The child explained, "Because people get sick when it's too cold; penguins get sick it's too warm!"

This child also knew that some medicine can kill certain kinds of germs but not others. For instance, when she was told that her eyes seemed pink one morning, she asked, "Are my eyes crusty too? Do you have to give me the eye-drops?" (age 3 years 10 months). As it turned out, her mother had explained to her during her previous episode of conjunctivitis that the medicine in the eye-drops could kill only the kind of germ that causes pink and crusty eyes; that it could not kill the kind of germ that causes only pink but not crusty eyes. This distinction between bacterial and viral infection was of great interest to her because she hated eye-drops.

Her knowledge of germs, infections, and germ-killing medicine seems to have behavioral consequences. At age 3 years 10 months, when her pink eyes turned out to be also crusty, her mother had a hard time (as usual) convincing her to cooperate with the administration of the eye-drops. Until the mother offered the following explanation, that is. She explained, “This morning, you let me put some eye-drops in your eyes. The medicine killed some of the germs, and your eyes are now less pink and crusty. But there are still germs in your eyes. If you don’t kill the rest with more eye-drops, the germs will split into more baby germs, and they will make your eyes pinker and more crusty again.” This explanation seemed to be effective enough to get the child lie still for the mother to administer the eye-drops, although not enough to stop the child from cringing in anticipation of the pain inflicted by the eye-drops. This child’s knowledge of germs and illness also seems to be useful in other ways. For instance, she is very good about brushing her teeth twice a day and washing her hands before meals. When she discovered that someone she knew brushed his teeth only before at bedtime, she told him, “You should brush your teeth in the morning too. When you brush you teeth at night, you can’t brush all the bad germs and food off. The bad germs can split into baby germs when you sleep. So, there will be lots of germs in you teeth in the morning!” (age 3 year 11 months).

Her knowledge of germs inside the human body also seemed quite sophisticated. For instance, when she scraped her knees or had some other minor wounds, she often talked about the pink and slightly swollen area around the wound, She would explain to whoever might be interested that there were still bad germs in the wound; that white blood cells were needed to kill the germs; that the wounded area was pink and swollen because the body had to let more blood--which carried white blood cells--to go there. In short, this child seemed to understand some biological mechanisms in this domain. Briefly, she seemed to know that germs are biological kinds that can live and die; that different germs can thrive in different conditions (e.g., penguin germs in warm weather; human germs in cold weather); that germs can reproduce by dividing into baby germs; that germs need nutrients for survival and reproduction; that germs can be killed by medicine and white blood cells; that dead germs are harmless.... This set of beliefs allowed her to reason about the causes, treatments, and symptoms of infections quite coherently and sensibly.

We want to make two points with this case study. First, Understanding and making use of biological causal mechanisms for reasoning about biological phenomena are possible even during the preschool years, if appropriate input from adults is available. So, for most children, the relatively late emergence of an autonomous biology--compared to naive mechanics--may have to do with the timing of input from science education rather than some domain-general cognitive limitations that prevent children from understanding simple biological causal mechanisms.

This brings us to the second point. Namely, the input for developing an understanding of uniquely biological causal mechanisms is probably not available to most children in their everyday life. In fact, we would venture as far as suggesting that an understanding of biological causal mechanisms is a luxury rather than a necessity during early and middle childhood.

Children can do quite well in predicting biological phenomena by learning about causal agents and input-output relations. When pressed to be explicit about the causal chain of events between the input and output, they can always fall back on mechanical causality. A case in point: The 4-year-old in this case study once explained to her mother why she could not sit up straight in a restaurant. (The child and her father had just picked up the mother from the airport.) She explained, “When you were in Washington, D.C. at your meeting, I started coughing and having a runny nose. Now there are so many germs moving this way and that way! They keep pushing me this way and that way, so I can’t sit still.” She then plopped down on her mother’s lap.

How School-Age Children Explain the “Incubation of Germs” Phenomenon

We (Au & Romo, 1996) asked 35 8- and 9-year-olds, "There are a few germs on a piece of fish inside a plastic bag. What will happen in a couple of days? Will there be more germs, fewer germs, or the same number of germs? Why?" About 26% of the children explained their predictions about the number of germs by invoking mechanical causality. Some examples are: "Same number of germs--because no germs can get through the plastic;" "More germs--because the fish will get more germs from the plain plastic bag. There might be dirt in that bag." About 17% correctly explained that there would be more germs because the germs would divide or multiply.

We also asked these children to consider, "Some bad germs got inside a kid's body. She felt okay for a day. But then the next day she started to feel sick all over her whole body. Why did it take a whole day for her to feel sick after the germs got inside her body?" Most of the children failed to give any meaningful explanation. But 34% of them did explain either that it took time for enough germs to get inside the girl's body or that it took time for the germs to get to different parts of the girl's body. Only 6% of them explained that it took time for the germs to multiply/reproduce inside the girl's body. There seemed, then, to be considerable interest in the paths traversed by the cold germs (i.e., getting into the body, going to different parts of the girl’s body) and the time required by such traveling. Our findings about food spoilage and contagion are consistent with Springer and Belk’s (1994) finding that some preschoolers and most 7- and 8-year-olds recognized the need for physical contact between a contaminant-carrying bug and food for the food to become contaminated. That is, most school-age children seem to believe that the mechanical paths traced by germs and/or contaminants are crucial for predicting whether contagion/ contamination will occur.

How School-Age Children Explain HIV Transmission

In assessing an experimental AIDS curriculum for fourth to eighth grade children, we asked children to explain their judgments of AIDS risk in the novel situations (Au & Romo, 1996). The experimental curriculum focused on a biological causal mechanism of HIV transmission, and so we expected that it would get children to mention the biology of HIV more than an existing curriculum would. We divided children’s explanations into these four categories:

(1) Mentioning the biology of HIV (die, survive, or reproduce)
E.g., "I said no because the saliva on the toothbrush bristles connected with air, so the AIDS in the saliva are dead;" "No, because it dies in the water. We always rinse with water and it [HIV on a toothbrush] dies;" "No, because AIDS can die in water."

(2) Mentioning the mechanical path traversed by the HIV

E.g., "Because if you wipe a person who has a bloody nose and you have a cut on your hand, the infected blood can get into you;" "The AIDS virus can get from the needle to the other person."

(3) Mentioning the media (substances surrounding the HIV)

E.g., "No, because there is no blood involved;" "Yes, because you can only get AIDS through blood."

(4) No or irrelevant/uninformative explanation

E.g., "I said no because you can't get AIDS by tattooing anywhere, maybe something else."

About 46% of the explanations invoked mechanical causality to talk about the path traversed by the AIDS virus. Only 17% mentioned the biology of the AIDS virus; only 11% mentioned just the media of the virus. The remaining 26% were "I don't know" or irrelevant explanations. Interestingly, children's tendency to offer a mechanical causal explanation did not vary much across grades or conditions (experimental vs. existing curriculum), even though the experimental curriculum succeeded in getting children to give biological explanations more often. These findings suggest that the tendency to invoke mechanical causality to explain AIDS--and perhaps more generally infection--transmission is rather robust during middle childhood and early adolescence.

Interim Conclusions

In this section, we have heard from children directly how they explained various biological phenomena. Mechanical causality was often invoked in their explanations. This finding is in line with the suggestive evidence that school-age children tend to choose, in forced-choice tasks, mechanical causal explanations over other kinds of explanations (e.g., genetic, intentional, or vitalistic) for biological phenomena (Inagaki & Hatano, 1993; Springer & Keil, 1991). Despite young children's rather impressive knowledge about biological kinds, then, we need to be cautious in attributing the status of an autonomous theory to such knowledge structure (see also Atran, 1994, 1995; Carey, 1995; Solomon et al., 1996). We need to know what its domain-specific causal devices and mechanisms might look like. That was what we tried to find out in the two studies to be reported here.

STUDY 1: CHILDREN'S EXPLANATIONS FOR ILLNESS, FOOD SPOILAGE, DEATH, INHERITANCE

How robust is children's tendency to invoke mechanic causality in explaining biological phenomena? While our case study and the two larger studies just summarized suggest that children from a wide age range (age 3 to age 14) stretch their naive mechanics into the domain of biology, it is obvious that we need more comprehensive evidence. In this study, we set out to listen to more children talking about more biological phenomena.

Method

Subjects

105 children (48 boys, 57 girls) in kindergarten through sixth grade were interviewed at their school, which was a parochial school serving primarily a low-income, Latino community in East Los Angeles. We chose this school because we were interested children's intuitive explanations for illness causation, food spoilage, death, and genetic inheritance. Two teachers at the school told us that the children had received very little, if any, health instruction either at

home or school, and that the school was in the process of developing a health education program. The sample size and mean age (and age ranges) in each grade were: 22 kindergartners, 5;8 (i.e., 5 years 8 months, ranging from 5;1 to 6;5), 14 first graders, 6;6 (6;2 to 7;2), 18 second graders, 7;6 (7;0 to 8;8), 15 third graders, 8;7 (8;2 to 9;2), 16 fourth graders, 9;7 (9;2 to 10;6), 10 fifth graders, 10;8 (10;5 to 11;7), 10 sixth graders, 11;7 (11;2 to 12;2).

Procedure

Children were interviewed individually in a quiet corner of their school. Each interview lasted about 10-15 minutes and was audiotaped and later transcribed. During the interview, an experimenter showed a child colored drawings depicting four stories (illness, food spoilage, death, inheritance). For each story, the experimenter narrated the picture(s) according to a well-rehearsed script and then asked a set of yes/no and open-ended questions about the story. The order of the stories was randomized and counterbalanced across children.

To create a comfortable atmosphere for the younger children, we sat next to the children to share a "picture book" (i.e., our stimulus book). To keep children interested in this book-reading task, some of the pictures included pop-up details (e.g., lifting a paper hat off a baby's head to examine her hair color, opening a freezer door to look inside). All children were interviewed according to the same protocol and using the same stimulus book.

We always followed up our yes/no questions with open-ended ones (e.g., "Why do you think that happened?"). To encourage children to tell us more, we probed for additional information after each explanation offered by a child (e.g., "That's interesting. Can you explain a little more about how that works?"). We probed only as long as each child had new information to offer. So, when children repeated a previous response, said that they had finished answering or didn't know the answer to the question, or changed the topic of the question, we moved on to the next question in the story or to the next story.

All interviews were transcribed and then coded according to the coding systems to be described presently. Because the questions and coding systems vary considerably from story to story, we will present the stimulus stories, questions, coding systems, and results one story at a time.

ILLNESS

Story and Questions

Scene 1: (a smiling boy talking to a girl holding a handkerchief to her face): "This is a picture of John and this is Mary. John is visiting Mary today. But poor Mary had a cold. She was sneezing and sneezing, and some bad germs got into John's body. But John felt fine, and they played for a little while, and then he went home."

Scene 2: (John holding his hand to his throat looking unhappy): "The next day when John woke up, he had a sore throat! Now remember when John was playing with Mary? Some bad germs got into his body, yet he felt fine. But the next day, he woke up with a sore throat. Why do you think that happened? **Why did it take a whole day for John to get a sore throat?**"

Scene 3: (John lying in bed looking miserable): "That night, John felt worse. Not only did his throat hurt, but now his ears hurt, his head hurt, and his whole body felt tired all over. Why do you think that happened? **Why did John feel sick all over?**"

Coding System

(1) "Biology" of Germs or White Blood Cells (including biological processes or animate functions such as growing, dying, reproducing, fighting, eating)

E.g., "The germs are growing and growing and making him more sick;" "It takes time for the cells to die off when bacteria strikes;" "Maybe the virus gets into one of his cells, and the cells keep reproducing, and then he will get more germs;" "The germs needed time to travel when they fight with your white blood cells, and then take effect."

(2) Explicit Mechanical Transfer of Germs

E.g., "Germs spread all over his body;" "The germs went into his throat;" "Germs settle in;" "Germs barely got in;" "It takes a while for the germs to get there."

(3) Explicit Movement of Unspecified Entities (e.g., sickness, cough, sneeze, it, they)

E.g., "He got sick because it went into his neck;" "The sneeze little by little came in through his body;" "The cough went all through his body and made him sick."

(4) Only People's Behaviors or Characteristics

E.g., "Mary sneezed on him;" "When he was talking to Mary, it got all over him;" "Mary was sneezing/ had a cold/ wasn't feeling well;" "John was talking to/ visiting Mary;" "John was playing and talking too much/ didn't rest/ didn't take medicine/ didn't wear a jacket/ went outside too long;" "The body gets weaker and weaker;" "He might have been healthy enough that it, well, because it takes time for colds and other sorts of sicknesses to take over your immune system;" "He did not feel he had the germs....and then in the morning, he realized that he was cold and he got sick."

(5) Other/Irrelevant/ Uninformative/Other/No Explanations

Category 1 (biology) supersedes Category 2 (explicit mechanical transfer), which supersedes Category 3 (movement of unspecified entities), which in turn supersedes Category 4 (people). This coding system was applied to both questions: "Why did it take a whole day (or, in Study 2, "so much time") for John to get a sore throat?" and "Why did John feel sick all over (or, in Study 2, "in so many parts of his body")?" Responses from all of the children in this and the next study were coded by the same coder. A second coder went over 33% (85 out of the 260 children in these two studies combined) of the responses independently for the first question and 38% of the responses for the second question. The two coders agreed on 92% and 91% of the cases respectively (Cohen's Kappas = 0.89 and 0.86).

Results

Only 6% of the 105 children in this study talked about the "biology" of germs or white blood cells (dying, growing bigger/stronger, breeding, fighting, eating) when they tried to explain "Why did it take a whole day for John to get a sore throat?" Only 4% of the children did so when they tried to explain "Why did John feel sick all over?" This tiny minority of children came from second through sixth grade classes (i.e., age seven and older).

By contrast, 35% of the children invoked mechanical transfer of germs to explain why it took a whole day for John to get a sore throat (e.g., "The germs went into his throat;" "It takes a while for the germs to get there"), and 42% did so to explain why John felt sick all over (e.g., "Germs spread all over his body"). This kind of explanation accounts for a majority of the older children's responses: 63% (fourth grade), 70% (fifth grade), 80% (sixth grade).

Many children--especially the younger ones--did not go much beyond talking about people's behaviors (e.g., "Mary was sneezing on him;" "John was talking to Mary") or characteristics (e.g., "the body gets weaker and weaker"). Overall, 30% of the children gave this kind of "people" explanations for the "took a whole day" question and 39% did so for the "sick all over" question. Such explanation talked about pertinent input-output relations at best; they did not offer any causal mechanism for the incubation period of infectious diseases. Table 1 summarizes the results on illness.

Insert Table 1 about here

FOOD SPOILAGE

Story and Questions

Scene 1: (a family gathering around the kitchen table, with parents wrapping up food in foil): "This is a picture of Karla and this is her family. They had fish for dinner tonight. Karla's mother and father are wrapping up the leftover fish. They wrapped the fish up tightly in foil, and put it in the freezer."

Scene 2: (kitchen scene, a covered plate is on the table and a covered plate is in the freezer): "The next day, when Karla went to the freezer, she saw the wrapped fish. But look--some wrapped fish was left on the table! It was left there all night long. **Do you think this fish has more germs than it did last night?** (if "Yes,") **How did more germs get on the fish?** (if "No,") **Why not?**" (experimenter opening the freezer) "What about the fish in the freezer? **Do you think this fish has more germs than it did last night?** (if "Yes,") **How did more germs get on the fish?** (if "No,") **Why not?**"

Coding System

(1) Biology of Germs
E.g., "The germs can die because it's very cold in the freezer;" "The germs will breed."

(2) Explicit Mechanical Transfer of Additional Germs
E.g., "Bugs got in and spread germs onto the fish;" "Germs are everywhere and get on the fish;" "The freezer is closed/sealed so germs cannot get on the fish;" "This has been sitting out, and it's been exposed to bacteria;" "Bacteria can flow through many places. Like if there's a broken plate, it can still flow in through the broken part."

(3) Implicit Mechanical Transfer of Germs: Discussing a source of additional germs without spelling out the mechanical path.
E.g., "The house is covered with germs and bacteria;" "They left it out on the table and outside there are germs;" "There is no germs in the cold and so it's protected from germs;" "The freezer doesn't have germs (and tables do)."

(4) Observable Events

4a. Relevant to Mechanical Transfer of Additional Germs: Mentioning possible sources or carriers of germs without using the term germ.

E.g., “The table is dirty;” “It was in the freezer, and the freezer is closed;” “The freezer door doesn’t have holes;” “Nobody touched it, sneezed on it, or coughed on it;” “Bugs could land on it.”

4b People’s Behaviors: Discussing food storage, food contamination via saliva.

E.g., “It was left it out on the table;” “They didn’t put it in the freezer;” “Karla’s family ate it and germs went onto the fish;” “It got rotten if you leave fish out.”

4a. Macroscopic Description of the Fish

E.g., “The fish stayed fresh;” “It’s in the freezer. It’s keeping it not to be rotten.”

(5) Other/Irrelevant/Uninformative/No Explanations

In this coding system, Category 1 (biology) supersedes Category 2 (explicit mechanical transfer), which supersedes Category 3 (implicit mechanical transfer), which in turn supersedes Category 4 (observable events). Within Category 4, 4a supersedes 4b, which supersedes 4c. This system was applied to responses given to “Do you think this fish has more germs than it did last night? (if “Yes,”) How did more germs get on the fish? (if “No,”) Why not?” for both the fish in the freezer and the fish left out on the table. Responses from all of the children in both Studies 1 and 2 were coded by the same coder. For the “fish on the table” question, a second coder went over 41% (105 out of the 260 children in these two studies) of the data independently, and the two coders agreed on 94% of the cases (Cohen’s Kappa = 0.92). For the “fish in the freezer” question, a second coder went over 38% of the data independently, and the two coders agreed on 85% of the cases (Cohen’s Kappa = 0.81).

Results

None of the children in this study, not even the sixth graders, invoked a biological causal mechanism to explain why there were more (or no more) germs in the fish after being left out on the table overnight. When asked to explain why there were more (or no more) germs in the fish after being stored in the freezer overnight, only 5 of the 105 children in this study--one each in second, third, four, fifth, and sixth grade--talked about the biology of germs (e.g., the germs died in the freezer).

Most of the children talked about observable events: potential source of germs (e.g., “the table is dirty”), people’s behaviors (e.g., “they didn’t put it in the freezer”), or the fish (e.g., “The fish stayed fresh/ became soggy”). These explanations reflect what children could readily observe in daily life: the input-output relation of food storage practices and the subsequent condition of food. By themselves, such explanations do not offer any causal mechanism for food spoilage or its prevention.

Of the 105 children, 26% did manage to offer explicit causal mechanisms for why the fish had more (or, for a small number of children, no more) germs after being left out on the table overnight. All of them invoked mechanical causality: “Bugs got in and spread germs onto the fish;” “Germs are everywhere and get on the fish;” “Germs couldn’t get in because the fish was wrapped;” and so forth. To explain why the fish in the freezer had no more (or, for a small number of children, more) germs after being stored there overnight, 32% of the 105 children offered an explicit causal mechanism. As noted earlier, only 5% of the children invoked biology (e.g., death of germs). The remaining 27% of the children invoked mechanics (e.g., "The freezer is closed/sealed so germs cannot get on the fish"). Table 2 summarizes the results on food spoilage.

Insert Table 2 about here

DEATH

Story and Questions

Picture of an insect: "What is this? That's right. And when [child's label for the insect in plural form, e.g., grasshoppers] are alive, we know that they can move, they can eat, and they can breathe. **Do you think a [child's label, e.g., grasshopper] can live forever? Why?**"

Coding System

(1) Biological Processes without Causal Mechanism (e.g., life Span)
E.g., "Part of cycle of life;" "Because you have to die sometimes;" "No one could live forever;" "Because everything has a time to die;" "It could get old."
(2) Mechanical Causes: Discussing outside mechanical forces that could crush the insect.
E.g., "If you step on it;" "Some animals could eat them;" "It got smashed."
(3) Other Observable Events without Explicitly Mentioning any Mechanical Cause of Death
E.g., "It gets hurt;" "It can be killed;" "Eating poison food and eating poison things;" "Go in water;" "It has no food;" "It's too hot or too cold;" "In winter when it's snowing."
(4) Other/Irrelevant/Uninformative/No Explanations

Category 1 (biological processes) supersedes Category 2 (mechanical), which supersedes Category 3 (other observable events). This coding system was applied to responses given to "Do you think a [child's label, e.g., grasshopper] can live forever? Why?" Only explanations from children who had correctly said "no" to the yes/no question were coded. Two coders independently went over all such explanations (altogether 224 explanations in Studies 1 and 2 combined). They agreed on 93% of the cases (Cohen's Kappa = 0.90).

Results

In this study, 25 (or 24%) of the 105 children incorrectly answered "yes" to the question, "Can grasshoppers/crickets/bugs live forever?" Twelve of them were in kindergarten, 7 in first grade, 4 in second grade, and 2 in fourth grade. This finding is reminiscent of our earlier finding that most children in a low-income Latino sample could not appropriately apply the attribute "will die someday" to plants and animals and not minerals and artifacts until age seven or so, lagging by about two years behind a university lab school sample (Au & Romo, 1996).

For the 80 children who answered "no," the two most popular kinds of explanations for why an insect cannot live forever were: life span (38%; e.g., "everything has a time to die") and mechanical causes (30%; e.g., "if you step on it"). As, shown in Table 3, explanations invoking life span became prevalent by second grade (about age seven). The percentage of children in each grade giving this kind of explanation varied from 36% to 60% in second through sixth grade. From kindergarten on, explanations invoking mechanical causality had a substantial presence, ranging from 20% to 57% in each grade. Most of the remaining children mentioned observable events that were not explicitly mechanical (e.g., "it has no food"). Note that neither the explanations invoking life span nor those mentioning non-mechanical events offered any explicit causal mechanism. Again, the only explanations that did so invoked mechanical causality.

Insert Table 3 about here

INHERITANCE

Story and Questions

Scene 1: (A black-haired woman holding a baby with a hat on): "This is a picture of a baby and this is his mom. What color hair do you think this baby has? Why don't you check under the hat and see? Yes, you were right--this baby has black hair just like his mother."

Scene 2: (A brown-haired woman holding a baby with a hat on): "Here's another baby and this is her mom. What color hair do you think this baby has? Let's check under the hat and see. Yes, you were right--this baby has brown hair just like her mother. Why do you think that happened? **Why does this baby and her mom have the same hair color?**"

Coding System

(1) Biology: Transfer of information through genes

E.g., "The genes from the mother and the chromosomes mix with the father and give the genetic code of the what the baby's going to look like."

(2) Explicit Mechanical Transfer of Substance to the Baby

E.g., "The mother's cells/genes/DNA/blood/food went into the baby;" "A piece of the mother's hair fell onto the baby;" "Blood mixed together and went into the baby;" "The baby has the mother's blood/genes;" "The mother painted or dyed the baby's hair."

(3) Only Implicit Mechanical Transfer of Substance to the Baby: Noting the mother-child proximity or connection during gestation/birth without explicitly mentioning transfer of substance.

E.g., "The baby was in the mommy's stomach;" "The baby was connected to the mother;" "The baby is a part of the mom;" "The baby was born from the mother;" "The baby came from the mother;" "They were a part of each other;" "The baby is part of the mother."

(4) Only Parent-Child Relations

E.g., "Because it's the mom's baby;" "Because they are related/the same family;" "Because they live together;" "Mothers/Parents and babies are supposed to have the same hair color" "Black hair is passed down from generation to generation;" "The mom and dad made the baby;" "The dad got the mom pregnant;" "Because the mother and the baby are both girls;" "Because they are Filipino."

(5) Other/Irrelevant/Uninformative/No Explanations

Category 1 (biology) supersedes Category 2 (explicit mechanical transfer), which supersedes Category 3 (implicit mechanical transfer), which in turn supersedes Category 4 (parent-child relations). This coding system was applied to children's explanations for "Why does this baby and her mom have the same hair color?" Responses from all of the children in both Studies 1 and 2 were coded by the same coder. A second coder went over 44% (114 out of the 260 children in these two studies) of the data independently, and the two coders agreed on 90% of the cases (Cohen's Kappa = 0.87).

Results

None of the children in this study, not even the sixth graders, invoked a biological causal mechanism to explain parent-child resemblance of hair color. (The example used for illustrating this category in the coding system was actually taken from Study 2.) While some children used scientific jargon such as genes, they only talked about parent-child relations and/or the mechanical transfer of genes without explaining how genes can determine hair color (i.e., by transfering information/instruction for making color pigment rather than by transfering color pigment itself). For example, one explanation coded as "parent-child relations" was, "My brother got the same genes as my dad, and I got the same genes as my mom." An example for the "mechanical transfer of genes" was "It could be through their genes....The genes go into the baby's body because they are from the same family."

Virtually all of the children talked about family relations in explaining parent-child resemblance in hair color. Some children did go beyond that to talked about an explicit causal mechanism, which was invariably mechanical in nature. They talked about explicit mechanical transfer of substances such as blood, food, part of the mother's body, mother's hair, genes, stuff carried by sperms/eggs, and so forth. Such explanations were prevalent among the third, fifth, and sixth (although not fourth) graders--ranging from 33% to 40% in each of these three grades (see Table 4).

Insert Table 4 about here

Another popular explanation type had to do with the baby's extreme proximity to the mother during gestation or birth (e.g., the baby was inside the mother/ came out of the mother). Even though such explanations did not talk about transfer of substance explicitly, they may have reflected beliefs about such transfer (e.g., food, blood, body stuff) from the mother to the baby. The percentage of children giving this kind of explanation for each grade (K - 6) ranged from 18% to 50%, accounting for 30% of children's responses in this study.

CONCLUSIONS FROM STUDY 1

Several conclusions can be drawn from these findings pertaining to four different biological phenomena: illness, food spoilage, death, inheritance. First, children very rarely, if at all, invoked uniquely biological causal mechanisms in their attempt to explain these phenomena. Those who did tended to come from the upper grades and to use scientific jargon--probably reflecting input from science classes rather than folk beliefs developed from everyday experience. In other words, there is little evidence that kindergarteners or grade school children have any bona fide folkbiology--if inclusion of domain-specific causal mechanisms is to be considered crucial for any folk theory. Second, as Carey (1985, 1991, 1995) would have predicted, many children talked about people's behaviors, relations, characteristics. Such explanations, at best however, were about input-output causal relations. Such talk about people (and other observable events) generally offered no explicit causal mechanism for explaining the biological phenomena examined in this study. Third, when children managed to offer explicit causal mechanisms, they almost always invoked mechanical causality (e.g., movement of germs that can cause illness and food spoilage, mechanical forces that can cause death, transfer of substances that affect a baby's hair color).

STUDY 2: A REPLICATION

The Children in Study 1 primarily came from low-income Latino families. Study 2 examined children's beliefs in other socioeconomic and ethnic groups.

METHOD

Subjects

In one school serving primarily middle class families, 66 children (18 boys, 48 girls) were interviewed. There were roughly 38% Anglo, 24% Filipino, and 20% Latino children; the remaining children came from other ethnic backgrounds. The sample size and mean age (and age ranges) in each of these grades were: 21 first graders, 7;1 (6;6 to 8;3), 20 third graders, 9;1 (8;7 to 9;10), and 25 fifth graders, 11;0, (10;7 to 12;5). In another school, which serves primarily lower-middle class families, 89 children (41 boys, 48 girls) were interviewed. The ethnic make-up of the students was roughly 17% Anglo, 52% Filipino, and 31% Latino. The sample size and mean age (and age ranges) in each of these grades were: 19 kindergartners, 5;8 (5;4 to 6;7), 22 first graders, 6;9 (6;6 to 7;4), 19 third graders, 8;8 (8;3 to 9;3), 16 fifth graders, 10;8, (10;4 to 11;4), and 13 seventh graders, 13;1 (12;6 to 13;4).

Procedure

The procedure was the same as that of Study 1, except for some wording changes in the research protocol for the illness, food spoilage, and death stories. (The protocol for the inheritance story remained unchanged.)

Illness. In Study 1, some children did not talk about the incubation period even though we had asked them, "Why did it take a whole day for John to get a sore throat?" Many of them seemed to treat our question as, "Why did John get a sore throat?" In Study 2, we asked instead, "Why did it take so much time for John to get a sore throat?" Also, in Study 1, we had asked, "Why did John feel sick all over?" Again, some children seemed to ignore the "all over" part of the question. In Study 2, we asked instead, "Remember here in the morning, he felt a little sick just in his throat. But that night, John felt sick in many parts of his body. So how do you think that happened? Why did John feel sick in so many parts of his body?"

Food Spoilage. In Study 1, we had asked, "Do you think this fish has more germs than it did last night? (if "Yes,") How did more germs get on the fish? (if "No,") Why not?" Our probe for a "yes" answer may have biased children to talk about mechanical transfer of additional germs because of the wording in the probe (i.e.,. "get on"). In Study 2, we asked instead, "Do you think this fish has more germs than it did last night? (yes/no) Why do you think so?"

Death. In Study 1, the questions "Do you think grasshopper/crickets/bugs (child's label) can live forever? Why?" did not elicit very much talk about possible causes of death. In Study 2, we added, "What are some ways a grasshopper/cricket/bug could die?"

RESULTS

Illness

The main findings of Study 1 on illness were replicated with these two samples from more diverse ethnic and higher socioeconomic backgrounds. That is, only a small number of children--mostly in the upper grade--talked about the biology of germs to explain the incubation period of an infectious disease and the spreading of symptoms to different parts of the body. By contrast, a substantial number of children invoked mechanical causality to talk about the movement of germs when they tried to explain these phenomena. The remaining children tended to talk only about what they can readily observe in daily life. Table 5 summarizes the results on illness in this study.

Insert Table 5 about here

Food Spoilage

The main findings of Study 1 on food spoilage were replicated in this study with one exception. Namely, most of the 25 fifth graders in the school serving primarily middle-class families talked about the biology of germs (e.g., death, breeding) when they tried to explain why there would be more (or no more) germs on the fish. About the fish that was left out on the table overnight, 72% of these fifth graders talked about a biological causal mechanism; about the fish that was stored in the freezer, 76% did so. So, these children outperformed their peers and older children in the low-income sample of Study 1 (fifth and sixth graders) and those in the lower-middle class sample of this study (fifth and seventh graders). As it turned out, the fifth-graders in the middle-class sample had recently seen a film on germ multiplication and the environments (at various temperatures: body temperature, room temperature, hot and cold places) where germs can live and die. Such school input was rare or entirely absent in the low-income sample, the lower-middle class sample, and in the first and third grade of this middle-class sample. These findings are consistent with our speculation (noted earlier) that the relatively late emergence of an autonomous biology--compared to that of naive mechanics --may have much to do with the timing of science education input. The results on food spoilage for this study are summarized in Table 6.

Insert Table 6 about here

Death

In this study, ten of the 89 children (or 11%) from the lower-middle class sample and one of the 66 children (or 2%) in the middle class sample incorrectly answered “yes” to the question, “Can grasshoppers/crickets/bugs live forever?” All but one of these children were in either kindergarten or first grade.

As in Study 1, for the children who answered “no,” the two most popular kinds of explanations for why an insect cannot live forever were: life span (26% for the lower-middle class sample and 42% for the middle class sample) and mechanical causes (30% and 52%, respectively for the two samples). Most of the remaining children mentioned observable events that were not explicitly mechanical (e.g., “it has not food”). Again, neither the explanations invoking life span nor those mentioning non-mechanical events offered any explicit causal mechanism. The only explanations that did so invoked mechanical causality. Table 7 summarizes the results on death for this study.

Insert Table 7 about here

Inheritance

Only one child (a seventh grader in the middle-class school) among the 155 children in this study talked about the transfer of information about hair color from the mother to the baby: "The genes from the mother and the chromosomes mix with the father and give the genetic code of the what the baby's going to look like." The use of jardon speaks clearly for the influence of science education; it certainly does not look like something spontaneously constructed by a child from everyday experience.

Most of the children's explanations fell roughly equally often into one of these three categories: explicit mechanical transfer of substances (28% for the lower-middle class sample, N=89; 18% for the middle class sample, N=66), mother-child proximity during pregnancy or birth (26% and 30% respectively), and only parent-child relations (24% and 35% respectively). Again, when children explicitly talked about a causal mechanism for mother-child resemblance of hair color, they virtually always talked about mechanical transfer of substance such as blood, body parts, hair, and food. Table 8 summarizes the results on inheritance for this study.

Insert Table 8 about here

INDIVIDUAL CHILDREN'S RESPONSE PATTERNS

Do most children invoke mechanical causality to explain biological phenomena some of the time? Or, do most of the "mechanical" explanations found in these two studies concentrated on the same group of children? What about explanations invoking biological causal mechanisms? What about explanations that focus on only people's behaviors, characteristics, relations, or other observable events? To address these questions, we computed the number of explanations in these three categories given by each child across biological phenomena.

Included as "biological causal mechanisms" are: biology of germs for the illness and food spoilage stories, and transfer of information/instruction about hair color for the inheritance story. (The death story is not included because no child offered any truly biological causal mechanism for that phenomenon.) Table 9 presents the percentage of children in each grade, with Studies 1 and 2 combined, giving various numbers of explanations invoking a biological causal mechanism. Overall, 80% of children gave no such explanation (N = 260). Only from second grade on did some children manage to offer at least one such explanation (possible maximum = 5).

Insert Table 9 about here

Included as "mechanical causal mechanisms" are: explicit mechanical transfer of germs for the illness and food spoilage stories, mechanical forces that can cause death, and mechanical transfer of substances from mother to baby. In sharp contrast to the pattern of results for "biology" explanations, 77% of the children invoked mechanical causality at least once. They gave anywhere from one to five such explanations (maximum = 6; see Table 9).

Included as "Only people's behaviors, characteristics, relations, and other observable events" are: only people's behaviors and characteristics for the illness story, only observable events for the food spoilage story, only observable events without explicit mention of mechanical forces for the death story, and only parent-child relations for the inheritance story. Like mechanical causality, people's behaviors and other observable events were invoked as the sole explanation for at least one biological phenomenon by 77% of the children. These children gave anywhere from one to six such explanations (maximum = 6; see Table 9).

Taken together, these patterns of results suggest that most of children invoke mechanical causality to explain a biological phenomenon some of the time. Most of the children also sometimes talk only about people's behaviors and other observable events. Finally, most children invoked no biological causal mechanism in these two studies.

CONCLUDING REMARKS

Now we feel that we have probably earned the privilege to put quotation marks around "folkbiology" in the title of this chapter. Our case study of a preschool child's quest for biological knowledge, our survey of folk explanations for illness and in medical anthropology research, our review of previous experimental studies of conceptual development in the domain of biology, and the two new studies reported here all converge to the same conclusions. First, children and adults do not seem to construct uniquely biological causal mechanisms from their everyday experience. If inclusion of domain-specific causal devices or mechanisms is crucial for determining whether a set of folk beliefs qualifies as a folk theory, then most children and perhaps even adults probably do not develop a "folkbiology" unless given science input.

We must confess that we oscillate almost daily between thinking that: (1) children clearly have no folk theory in the domain of biological kinds, and (2) we are being too harsh. One difficulty with taking a hard line on folkbiology is that we may be forced to say that children (and most adults for that matter) do not have a naïve psychology either. After all, research on naïve "psychology" to date seems to have focused entirely on causal relations among beliefs, feelings, and behaviors (e.g., Wellman, 1990; Wellman & Gelman, in press;). It has offers no clue for what folk psychological causal mechanisms might look like. So, in our more lenient moments, we ponder whether a foundational theory must include domain-specific causal mechanisms. Might inclusion of input-output causal relations and causal agents suffice? Should some day enough researchers be willing to abandon inclusion of domain-specific causal mechanisms as a necessary criterion for folk theories, or more specifically, for folkbiology (e.g., Atran, in press), we will probably be willing to credit children as well as adults with folkbiology. But until then….

Second, Carey (1981, 1991, 1995) cannot be more correct in saying that children draw on their knowledge of people (and other everyday observable behaviors) to reason about biological phenomena. However, such explanations are at best about input-output causal relations. They do not provide causal mechanisms per se.

Third, when children do talk about causal mechanisms in their attempts to make sense of biological phenomena, they almost always fall back on a folk theory that they know well--namely, naive mechanics. Such reliance on mechanical causality is pervasive; it is evident among children across a rather wide age range (from preschool years through adolescence), different ethnic backgrounds, and different socioeconomic backgrounds. To be honest, we were quite surprised that our Study 2 replicated virtually all of the main findings of Study 1. Our team of interviewers and transcribers was convinced that we would find major differences between our low-income sample (Study 1) and the two samples from higher socioeconomic backgrounds (Study 2). They noted that the children from the low-income sample were hard to interview because the children, especially the younger ones, would just sit there and say very little (see also Brice, 1983). Nonetheless, when those children talked--however inarticulate they may have seemed--they revealed much the same kinds of beliefs as the children from the higher-income samples.

We rest our case.

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Table 1: Percentage of Children in Study 1 Giving Various Kinds of Explanations for Illness

INCUBATION PERIOD OF COLDS

GRADE=	K	1st	2nd	3rd	4th	5th	6th	All

N =	22	14	18	15	16	10	10	105
EXPLANATION TYPE								
Biology	0	0	17%	0	6%	10%	10%	6%
Movement of Germs	14%	14%	17%	27%	63%	70%	80%	35%
Movement of Sickness, etc.	5%	0	22%	7%	6%	10%	0	8%
People's Behaviors, etc.	55%	57%	33%	60%	25%	10%	10%	39%

SPREADING OF SYMPTOMS TO DIFFERENT PARTS OF THE BODY

GRADE=	K	1st	2nd	3rd	4th	5th	6th	All
N=	22	14	18	15	16	10	10	105
EXPLANATION TYPE								
Biology	0	0	17%	0	0	10%	0	4%
Movement of Germs	27%	7%	28%	47%	63%	70%	80%	42%
Movement of Sickness, etc.	0	7%	17%	13%	6%	10%	0	8%
People's Behaviors, etc.	36%	50%	33%	27%	19%	10%	20%	30%

Table 2: Percentage of Children in Study 1 Giving Various Kinds of Explanations for Food Spoilage

FISH ON TABLE

GRADE=	K	1st	2nd	3rd	4th	5th	6th	All
N =	22	14	18	15	16	10	10	105
EXPLANATION TYPE								
Biology	0	0	0	0	0	0	0	0
Explicit Movement of Germs	18%	7%	50%	27%	25%	20%	30%	26%
Implicit Movement of Germs	0	0	6%	0	0	0	0	1%
Observable Events								
relevant to mechanical transfer	36%	36%	11%	40%	31%	60%	50%	35%
people's behaviors	27%	43%	28%	13%	44%	20%	20%	29%
condition of fish	0	7%	0	13%	0	0	0	3%

FISH IN FREEZER

GRADE=	K	1st	2nd	3rd	4th	5th	6th	All
N =	22	14	18	15	16	10	10	105
EXPLANATION TYPE								
Biology	0	0	6%	7%	6%	10%	10%	5%
Explicit Movement of Germs	9%	21%	33%	20%	38%	30%	50%	27%
Implicit Movement of Germs	0	7%	6%	13%	0	0	10%	5%
Observable Events								
relevant to mechanical transfer	45%	29%	22%	33%	50%	40%	30%	36%
people's behaviors	23%	29%	28%	13%	6%	10%	0	17%
condition of fish	0	0	0	7%	0	0	0	1%

Table 3: Percentage of Children in Study 1 Giving Various Kinds of Explanations for an Insect's Death

GRADE=	K	1st	2nd	3rd	4th	5th	6th	All
N=	10	7	14	15	14	10	10	80
EXPLANATION TYPE								
Life Span/ Getting Old	0	14%	36%	40%	50%	60%	50%	38%
Mechanical Causes	40%	57%	21%	20%	29%	30%	30%	30%
Observable Nonmechanical Causes	40%	0	21%	20%	14%	10%	10%	18%

Table 4: Percentage of Children in Study 1 Giving Various Kinds of Explanations for Mother-Child Resemblance of Hair Color

GRADE=	K	1st	2nd	3rd	4th	5th	6th	All
N =	22	14	18	15	16	10	10	105
EXPLANATION TYPE								
Biology	0	0	0	0	0	0	0	0
Explicit Transfer of Substance	14%	7%	11%	33%	19%	40%	40%	21%
Implicit Transfer of Substance	18%	21%	33%	33%	25%	50%	40%	30%
Parent-Child Relations	18%	36%	39%	27%	56%	10%	20%	30%

Table 5: Percentage of Children in Study 2 Giving Various Kinds of Explanations for Illness

INCUBATION PERIOD OF COLDS

	Middle Class Sample			Lower-Middle Class Sample					
GRADE=	1st	3rd	5th	K	1st	3rd	5th	7th	ALL
N =	21	20	25	19	22	19	16	13	155
EXPLANATION TYPE									
Biology	0	5%	32%	0	0	5%	13%	31%	10%
Movement of Germs	33%	60%	48%	21%	23%	42%	38%	38%	38%
Movement of Sickness, etc.	10%	5%	0	5%	5%	0	6%	8%	5%
People's Behaviors, etc.	33%	20%	20%	63%	59%	21%	38%	23%	35%

SPREADING OF SYMPTOMS TO DIFFERENT PARTS OF THE BODY

	Middle Class Sample			Lower-Middle Class Sample					
GTADE=	1st	3rd	5th	K	1st	3rd	5th	7th	ALL
N =	21	20	25	19	22	19	16	13	155
EXPLANATION TYPE									
Biology	0	0	24%	0	0	5%	6%	8%	6%
Movement of Germs	38%	70%	56%	21%	23%	58%	56%	69%	48%
Movement of Sickness, etc.	14%	5%	8%	5%	14%	11%	19%	8%	10%
People's Behaviors, etc.	19%	25%	12%	68%	59%	21%	19%	15%	30%

Table 6: Percentage of Children in Study 2 Giving Various Kinds of Explanations for Food Spoilage

FISH ON THE TABLE

	Middle Class Sample			Lower-Middle Class Sample					
GRADE=	1st	3rd	5th	K	1st	3rd	5th	7th	ALL
N =	21	20	25	19	22	19	16	13	155
EXPLANATION TYPE									
Biology	0	0	72%	0	0	0	6%	0	12%
Explicit Movement of Germs	14%	30%	16%	26%	14%	63%	50%	54%	31%
Implicit Movement of Germs	5%	0	4%	0	14%	0	6%	8%	5%
Observable Events									
relevant to mechanical transfer	33%	40%	0	16%	32%	21%	38%	23%	25%
people's behaviors	29%	25%	8%	53%	18%	16%	0	8%	20%
condition of fish	5%	5%	0	0	0	0	0	8%	2%

FISH ON THE TABLE

	Middle Class Sample			Lower-Middle Class Sample					
GRADE=	1st	3rd	5th	K	1st	3rd	5th	7th	ALL
N =	21	20	25	19	22	19	16	13	155
EXPLANATION TYPE									
Biology	0	10%	76%	0	0	11%	6%	15%	17%
Explicit Movement of Germs	14%	20%	12%	11%	18%	42%	50%	23%	23%
Implicit Movement of Germs	0	5%	4%	16%	9%	5%	6%	8%	6%
Observable Events									
relevant to mechanical transfer	29%	35%	0	32%	32%	21%	38%	23%	25%
people's behaviors	43%	25%	4%	37%	36%	11%	0	23%	23%
condition of fish	0	0	0	0	5%	0	0	8%	1%

Table 7: Percentage of Children in Study 2 Giving Various Kinds of Explanations for an Insect's Death

	Middle Class Sample			Lower-Middle Class Sample					
GRADE=	1st	3rd	5th	K	1st	3rd	5th	7th	ALL
N =	20	20	25	14	18	18	16	13	144
EXPLANATION TYPE									
Life Span/ Getting Old	24%	30%	64%	5%	9%	32%	56%	62%	38%
Mechanical Causes	62%	55%	36%	11%	27%	37%	38%	23%	39%
Observable Nonmechanical Causes	5%	15%	0	11%	14%	11%	0	15%	9%

Table 8: Percentage of Children in Study 2 Giving Various Kinds of Explanations for Mother-Child Resemblance of Hair Color

	Middle Class Sample			Lower-Middle Class Sample					
GRADE=	1st	3rd	5th	K	1st	3rd	5th	7th	ALL
N =	21	20	25	19	22	19	16	13	155
EXPLANATION TYPE									
Biology	0	0	0	0	0	0	0	8%	1%
Explicit Transfer of Substance	0	15%	36%	11%	9%	21%	50%	69%	24%
Implicit Transfer of Substance	38%	30%	24%	5%	45%	47%	19%	0	28%
Parent-Child Relations	38%	35%	32%	37%	27%	5%	25%	23%	28%

Table 9: Percentage of Children in Both Studies Giving Various Numbers of "Biological," "Mechanical," and "People/Observable Event" explanations

GRADE=	K	1st	2nd	3rd	4th	5th	6th	7th	ALL
N=	41	57	18	54	16	51	10	13	260
NUMBER OF EXPLANATIONS									
Biological									
0	100%	100%	78%	85%	88%	45%	80%	46%	80%
1	0	0	11%	15%	13%	18%	20%	38%	11%
2	0	0	6%	0	0	18%	0	15%	5%
3	0	0	6%	0	0	14%	0	0	3%
4	0	0	0	0	0	4%	0	0	1%
5	0	0	0	0	0	2%	0	0	0
Mechanical									
0	49%	37%	28%	19%	13%	6%	0	0	23%
1	22%	25%	28%	11%	13%	16%	20%	8%	18%
2	15%	25%	6%	24%	13%	31%	20%	38%	23%
3	10%	7%	39%	22%	56%	25%	20%	31%	21%
4	5%	5%	0	15%	6%	18%	10%	15%	10%
5	0	2%	0	9%	0	4%	30%	8%	5%
6	0	0	0	0	0	0	0	0	0
People/ Observable Event									
0	12%	7%	11%	28%	19%	43%	60%	23%	23%
1	20%	32%	33%	31%	6%	22%	10%	31%	25%
2	22%	26%	17%	13%	38%	25%	20%	31%	23%
3	20%	19%	28%	17%	31%	2%	10%	15%	16%
4	15%	7%	6%	9%	6%	4%	0	0	7%
5	7%	7%	6%	2%	0	2%	0	0	4%
6	5%	2%	0	0	0	2%	0	0	2%