



Title	YOUNG CHILDREN'S PERSONIFYING AND VITALISTIC BIOLOGY
Author(s)	INAGAKI, Kayoko; HATANO, Giyoo
Citation	乳幼児発達臨床センター年報, 16, 1-25
Issue Date	1994-03
Doc URL	http://hdl.handle.net/2115/25291
Type	bulletin (article)
File Information	16_P1-25.pdf



[Instructions for use](#)

YOUNG CHILDREN'S PERSONIFYING AND VITALISTIC BIOLOGY¹

Kayoko Inagaki

Chiba University

Giyoo Hatano

Dokkyo University

This article aimed at investigating the nature of young children's naive biology by reviewing a large number of studies conducted in our laboratories. More specifically, we tried in the first part of the article to answer the following two critical questions: What components does children's knowledge system for biological phenomena have before being taught systematically at school? Can the knowledge system be called naive biology? We proposed that young children's biological knowledge system has at least three components, that is, knowledge needed to specify the target objects or phenomena of biology, constrained analogies with knowledge about humans or other familiar animals as the source for inferring attributes or behaviors of biological kinds, and a vitalistic causal explanatory framework, and that these three constitute a form of biology. In the last part, we were concerned with the use, acquisition, and change of this naive biology. We claimed that it is readily used and is functional in children's lives, that its core is acquired based on specific cognitive constraints as well as the general mechanism of personification and the resultant vitalistic causality but it is differently instantiated and elaborated through activity-based experiences and shared beliefs and artifacts in the surrounding culture, and that it evolves into intuitive biology educated lay adults possess as its weaknesses are overcome by learning of school or scientific biology.

Young Children's Personifying and Vitalistic Biology

There has been a debate in recent years as to whether young children have acquired a form of biology. On the one hand, Carey (1985) claimed that children before around age 10 make predictions and explanations for biological phenomena based on intuitive psychology (i.e., intentional causality). According to her, young children lack the mind-body distinction, more specifically, do not recognize that our bodily functions are independent of our intention nor that biological processes which produce growth or death are autonomous. On the other hand, a number of recent studies have suggested that children possess biological knowledge at much earlier ages than Carey has claimed. Some developmentalists (e.g., Hatano & Inagaki, 1987) have asserted that the differentiation between psychology and biology occurs, if it does, much earlier than Carey (1985) assumed. Others have proposed that biological phenomena are con-

¹ This is an expanded and modified version of our paper, "Young children's naive theory of biology" by Hatano and Inagaki, to appear in *Cognition*, 1994, 50.

ceptualized differently from other phenomena from the beginning (e.g., Keil, 1992).

However, it should be noted that there are more agreements than disagreements among major investigators of young children's understanding of biological phenomena. All of them agree that young children possess "theories" (or cognitive entities equivalent to them) about biological phenomena, more specifically, concerning internal processes involved in the individual survival and reproduction of animals and plants, and their external behaviors and properties relevant to these processes. Here the term "theory" means a coherent body of knowledge that involves causal explanatory understanding. In other words, it is assumed that young children's bodies of knowledge about biological phenomena have something more than a collection of facts and/or procedures to obtain desired results (Kuhn, 1989). It is obvious that this conceptualization is a distinct departure from the Piagetian position, which assumed young children to be preoperational and thus incapable of offering more or less plausible explanations in any domain.

At the same time, however, none of the investigators have ever claimed that young children have acquired the modern science of biology. As Carey (1985) aptly put it, they are "totally ignorant of the physiological mechanisms involved" (p. 45). They know that input (e.g., eating too much) is related to output (becoming fat or upsetting the stomach), but nothing about what mediates them at physiological and/or biochemical levels. The debatable issue is whether they possess a version of endogenous biology, similar to ethnobiology or folkbiology, which is separated from psychology.

This paper is divided into two parts. In the first part, based on a large number of studies conducted in our laboratories, we will specify the contents of young children's theory-like knowledge system for biological phenomena, that is, what components are included in it. We will show that young children own three essential components that constitute a form of biology. In the last part, also by reviewing our experimental studies, we will be concerned with the use, acquisition, and change of young children's naive biology. Research on these issues has been scant, partly because it presupposes some specification of the contents of naive biology. We hope to further elucidate the nature of young children's biology, by presenting our empirical findings on these issues.

Components of Young Children's Biological Knowledge

We are convinced that the body of knowledge which young children possess about biological phenomena (e.g., behavior of animals and plants needed for individual survival; bodily process; reproduction and inheritance of properties to offsprings) has at least three components, and believe that these three constitute a naive biology (Inagaki, 1993b). The first is knowledge enabling one to specify objects to which biology is applicable; in other words, knowledge about the living-nonliving distinction, and also about the mind-body distinction. The second is a mode of inference which can produce consistent and reasonable predictions for attributes or behaviors of biological kinds. The third is a non-intentional causal explanatory framework for behaviors needed for individual survival and bodily processes.

Knowledge Needed to Specify Targets of Biology

Animate-inanimate distinction. An increasing number of recent studies have revealed that young children have the animate-inanimate distinction. Let us take a few examples. Gelman, Spelke, and Meck (1983) asked such questions as "Does X have a property of Y?" or "Can X do Y?" to children aged 3 to 5 years, using typical animates (i.e., a person and a cat) and inanimates (i.e., a rock and a doll or puppet) as targets. Four types of animate properties were used there: actions (e.g., walk, see), body parts (e.g., a mouth, a head), reciprocal actions (e.g., you talk to X/X talks to you) and mental-emotional states (e.g., think, feel sad). The results indicated that 3-year-olds as well as 4- and 5-year-olds made correct responses to questions for each of the four types of properties of each target object at about 90 percent or more of the time, and to questions for a person at 100 percent of the time. This illustrates that children aged 3 to 5 have not only rich knowledge about people but also knowledge needed to distinguish animate entities from inanimate ones.

Massey and Gelman (1988), using unfamiliar animate entities as target objects, found that preschool children can distinguish animals and inanimate objects in terms of whether they have a capacity for self-initiated movements or not. That is, 3- and 4-year-olds were shown photographs of unfamiliar objects, including mammals, non-mammalian animals, statues with familiar animal-like forms and parts, wheeled vehicles, and multipart rigid objects, and asked whether each of these objects could go up and down a hill by itself. These children were correct on about 85% of their first yes-no answers, indicating that they answered animals could go up and down a hill by themselves, while inanimate objects, even if they looked like animals, couldn't. This result was corroborated by analyses of children's individual patterns of responses; a great majority of them showed a pattern of responses which was best described by the rule, or its variant, that all animals can move by themselves and that all of the inanimate objects require an external agent in order to move. Analyses of explanations that the children gave spontaneously or in request for justifications of their yes-no responses suggested that these children tended to change the kind of their explanations depending upon the type of the object. When talking about animals, children often focused on parts that enable the target to move, such as, "It can move because it has feet," or referred to some general feature of the target's appearance, such as, "It's an animal because it has a face." For inanimate objects, such as wheeled vehicles or rigid objects, they also referred to parts enabling movement, such as, "It can roll down on its wheels," or to an agent needed to move the object, saying, "It needs a push and then it goes," or "You have to carry it down."

Based on these results, Gelman (1990) proposed a hypothesis that young children at their early ages possess skeletal principles focusing on "causal mechanism" enabling objects to move. In other words, these principles, which focus attention on those natural kinds that move on their own, the innards principle, and which draw attention to objects that do not move on their own, the external-agent principle, lead one to rapidly acquire knowledge about the animate-inanimate distinction. Gelman claims that the experimental evidence on the inside-outside of the object supported her hypothesis.

Most previous studies on the animate-inanimate distinction have concerned the

distinction between animals and non-living things, typically represented by the studies described above, and only a small number of studies have dealt with plants as living things. Studies concerning the animate-inanimate distinction in terms of whether the target object was alive provided the evidence that young children had difficulty in acknowledging that plants are alive (e.g., Richards & Siegler, 1984, 1986; Stevy & Wax, 1989). For example, Richards and Siegler (1984) reported that less than 20 percent of children aged 4 to 5 and only a half of children aged 6 to 7 showed the "living things" rule that humans, non-human animals and plants are alive, while non-living things are not. However, the term, "alive," for young children might not map that for adults (Carey, 1985), because it is ambiguous in a sense that it is used in varied ways (including metaphorical usages) in everyday life. In fact, Massey & Gelman (1988) found that the children who correctly judged whether each object could go up and down the hill failed in judging whether each was alive in considerable degree.

More recent studies examined, using more specific indicators other than the life status, whether young children recognize plants as distinct from nonliving things, and indicated that they can do so in some respects. For example, Inagaki (1993a) found that children before age 6 distinguish plants and animals from nonliving things in terms of growth, i.e., changes in size as time goes by. This study was an extension of Rosengren, Gelman, Kalish and McCormick (1991) which investigated children's differentiation between animals and artifacts in terms of growth; children of ages 4 to 6 were presented with a picture of a flower's sprout (or a new artifact or a young animal) as the standard stimulus picture, and were then asked to choose which of two other pictures would represent the same plant (or artifact or animal) a few hours later and several months/years later. Figure 1 shows an example of stimulus and choice cards for each of plants, artifacts and animals. As indicated in Figure 2, the children showed "invariance" patterns (i.e., no change in size both a few hours later and several months/years later for all the items) for artifacts but "growth" patterns (i.e., changes in size either/both a few hours later or/and several months/years later) for plants and animals. Backscheider, Shatz, and Gelman (1993) also reported that 4-year-olds recognize that, when damaged, both animals and plants can regrow, whereas artifacts can be mended only by human intervention.

That young children treat inanimate things differently from animals and plants is not sufficient for claiming that they have an integrated category of living things. Proof that they are aware of the commonalities between animals and plants is needed. By asking 5- and 6-year-olds whether a few examples of plants or those of inanimate things would show similar phenomena to those we observe for animals, Hatano and Inagaki (1994) found that a great majority of them recognized commonalities between animals and plants in terms of feeding and growing in size over time, and thus distinguished them from inanimate things. Moreover, many of them justified their responses by mapping food for animals to water for plants, such as "A tulip or a pine tree dies if we do not water it". For growing in size, a substantial number of the children offered a phenomenon of plants' getting bigger from a seed or a bud; there found children who referred to watering as corresponding to feeding as a condition for growth. For growth in number by reproduction, in addition, about a half of the children recognized

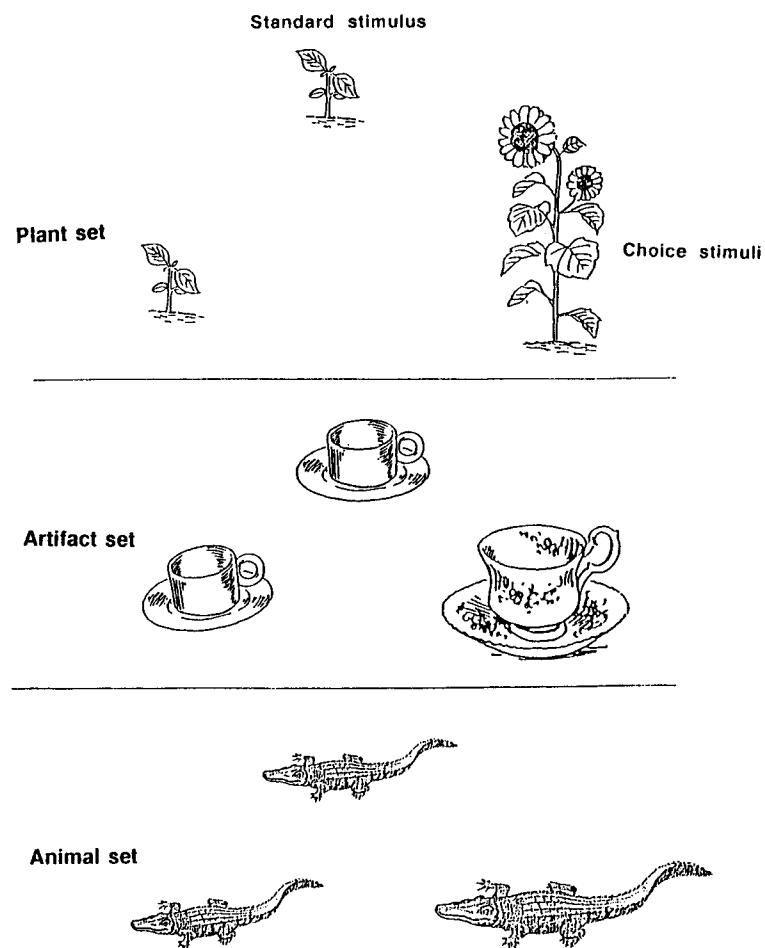


FIGURE 1 An example set of standard stimulus and choice stimulus cards for plants, artifacts, and animals.

the similarity between animals and plants, and a substantial number of them justified their responses by referring to seeds as similar to animals' increase by having babies or eggs, indicating that buds come out from seeds buried in the ground and grow in number (or produce many flowers); there also found children who seemed to regard plants' having flowers after flowers or becoming thickly covered by leaves as a similar phenomenon.

Springer and Keil (1991) indicated that preschoolers differentiated plants (and animals) from artifacts in terms of causal mechanisms involved in color transmission; they preferred natural biological mechanisms in color transmission for a flower and a dog, whereas they chose non-biological mechanical explanations for cans as plausible. Based on these and other related studies, we can conclude that children are able to acquire the living-nonliving distinction by age 6.

Mind-body distinction. Can young children distinguish between the body and the mind? Though studies dealing with this issue are small in number yet, the available

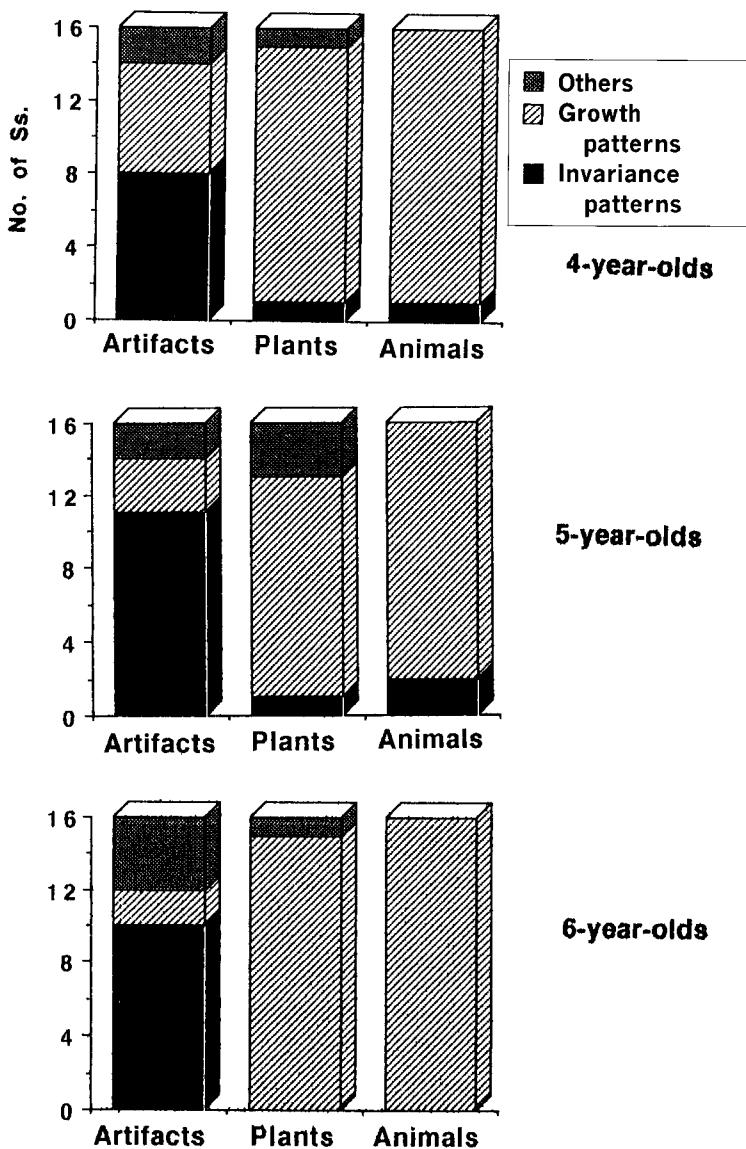


FIGURE 2 Distributions of three patterns for artifacts, plants and animals in each age group.

data show that the answer is Yes. That is, young children distinguish functions of body from those of mind, in other words, biological phenomena from social or psychological ones, both of which are observed among a subset of animate things. Springer and Keil (1989) reported that children of ages 4-7 consider those features leading to biologically functional consequences for animals to be inherited, while other sorts of features, such as those leading to social or psychological consequences, to be not. Here children listened to descriptions about two abnormal features that animal parents had, and then were asked whether the baby would be born with those features in normal or abnormal form. The result indicated that the children considered characteris-

tics leading to biologically functional consequences (e.g., a white stomach inside so they could eat a lot and stay strong) as inherited, and those leading to social or psychological consequences (e.g., a white stomach inside that made them feel angry a lot) as non-inherited. Siegal (1988) reported that children of ages 4-8 recognize that illness is caused not by moral but by medical factors; they have substantial knowledge of contagion and contamination as causes of illness. Inagaki and Hatano (1987) revealed that children of 5-6 years of age recognize that the growth of living things is beyond their intentional control. For example, a baby rabbit grows not because its owner wants it to but because it takes food. These findings all suggest that young children recognize the autonomous nature of biological processes.

An even more systematic study on the mind-body distinction was reported by Inagaki and Hatano (1993, Experiment 1). By interviewing children using a variety of questions, they showed that even children aged 4 and 5 already recognize not only the differential modifiability among characteristics that are unmodifiable by any means (e.g., gender), that are bodily and modifiable by exercise or diet (e.g., running speed), and that are mental and modifiable by will or monitoring (e.g., forgetfulness), but also the independence of activities of bodily organs (e.g., heartbeat) from a person's intention. Figure 3 shows the children's responses to the controllability of activities of bodily organs.

Another important piece of evidence for this distinction is young children's use of non-intentional (or vitalistic) causality for bodily phenomena but not for social-psychological ones; this point is discussed in a later section.

Personification as Means to Make Educated Guesses about Living Things

When children do not have enough knowledge about a target animate object, they can make an educated guess by using personification or the person analogy in a constrained way. Young children are so familiar with humans that they can use their

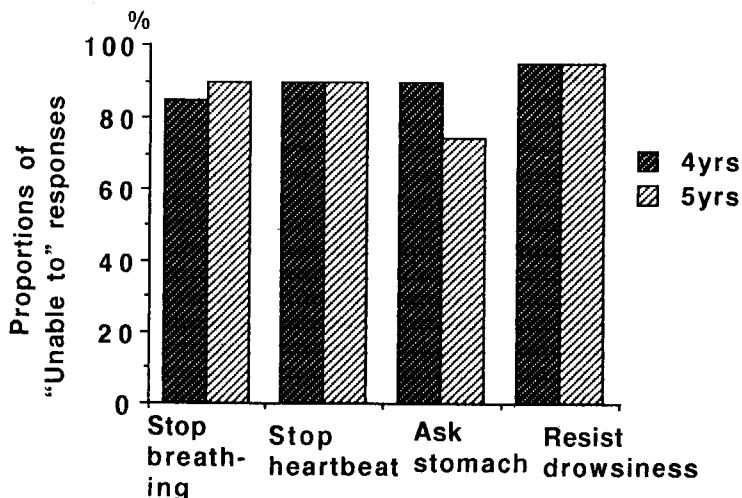


FIGURE 3 Children's responses to the controllability of activities of internal organs.

knowledge about humans as a source for analogically attributing properties to less familiar animate objects or predicting the reactions of such objects to novel situations, but they do not use knowledge about humans indiscriminately. In other words, they can use personification or person analogy in an adaptive way in that they generate answers without committing many overpersonifying errors. How is it possible for young children who have not acquired an articulated taxonomy of properties (e.g., all-living-thing properties, animal properties, etc.) to do so? They seem to be helped by two constraints when they transfer knowledge about humans to other animate objects.

One is a differential application or similarity constraint, which requires the target object to be more or less similar to a human in order for the person analogy to be applied to it. As Vosniadou (1989) insists, children tend to apply an analogy on the basis of salient similarity between the target and the source, though the "depth" of this perceived similarity varies with the richness and structuredness of the knowledge base children have. Generally, the closer the target object is biologically to a human being, the more often children recognize its similarity and thus apply the person analogy. In fact, some studies have found that young children attribute human characteristics to targets in proportion to the extent that they are perceived similar to people (Carey, 1985; Inagaki & Sugiyama, 1988).

The other constraint in young children's person analogy is a factual check or feasibility constraint that Inagaki and Hatano (1987) proposed. This requires that the predicted behavior of the target object through the person analogy be feasible, and that, if not, the prediction be rejected. They claimed that this constraint works after the person analogy is attempted, that is, one examines whether the analogical inference is tenable on the basis of factual knowledge about the target object. Even young children often know specific facts about "observable attributes" of an animate object, e.g., whether or not it has a mouth, walks, speaks to humans, etc. (e.g., Gelman, Spelke & Meck, 1983; Inagaki & Hatano, 1987). Thus they may use this knowledge to check the plausibility of predictions reached by the person analogy, even though the knowledge is not powerful enough to generate predictions in itself. Inagaki and Hatano (1987, 1991) provided evidence supporting this idea on the role of feasibility constraint in a process of personification.

In one of their studies (Inagaki & Hatano, 1991), children of age 6 were asked to predict a grasshopper's or tulip's reactions to three types of novel situations: (a) similar situations, in which a human being and the target object would behave similarly, and thus the person analogy generates predictions plausible to them in light of their specific knowledge, (b) contradictory situations, where the target object and a human would react differently, and predictions based on the person analogy contradict children's specific knowledge about the target, and (c) compatible situations, where the object and a human being would in fact react differently, but predictions obtained through the person analogy do not seem implausible to them. Example questions for each situation are as follows: "We usually feed a grasshopper once or twice a day when we raise it at home. What will happen with it if we feed it 10 times a day?" [In the case of a tulip, the word *water* was used instead of *feed*.] (a similar situation); "Suppose a woman buys a grasshopper. On her way home she drops in at a store with

this caged grasshopper. After shopping she is about to leave the store without the grasshopper. What will the grasshopper do?" (contradictory); "Does a grasshopper feel something if the person who has been taking care of it daily dies? [If the subject's answer is "Yes"] How does it feel?" (compatible).

Results indicated that for the similar situations many of the children generated reasonable predictions with some explanations by using person analogies, whereas they did not give personified predictions for the contradictory situations. As expected, they produced unreasonable predictions for the compatible situations, where they were unable to check the plausibility of products of person analogies because of the lack of adequate knowledge (e.g., about the relation between the brain and feeling).

What follows are example responses of two children for the grasshopper questions and for the tulip questions, respectively :

M. K. (6 years, 3 months): For the "too-much-eating" question of the similar situation, "The grasshopper will be dizzy and die, 'cause the grasshopper, though it is an insect, is like a person (in this point)"; for the "left-behind" question of the contradictory situation, "The grasshopper will be picked up by someone, 'cause it cannot open the cage." [*If someone does not pick up the cage, what will the grasshopper do?*]" "The grasshopper will just stay there." [*Why doesn't the grasshopper do anything? Why does it just stay there?*]" "It cannot (go out of the cage and) walk, unlike a person"; for the caretaker's death question of the compatible situation, "The grasshopper will feel unhappy."

Y. S. (6 years, 0 months): For the too-much eating question in the similar situation, "The tulip will go bad. [*why?*] If we water the tulip too much, it cannot drink the water so much, so it will wither"; for the left-behind question in the contradictory situation, "The tulip doesn't speak....Someone will bring the (potted) tulip to the police office, as a lost thing." [*If there is no one who does such a thing, what will the tulip do? Is there anything the tulip can do?*]" "The tulip cannot move, because it has no feet"; for the caretaker's death question in the compatible situation, "The tulip will surely be sad. It cannot say 'sad,' but it will feel so inside."

These illustrate well how these children applied knowledge about humans differentially according to the types of situations. Generally speaking, children generate reasonable predictions, using person analogies in a constrained way, and the person analogy may be misleading only where they lack (biological) knowledge to check analogy-based predictions.

Young children's frequent use of personification is not limited to biological inference, but is observed in other behavioral domains. However, it is a very useful tool in biological inference, because humans are a species of advanced animals, and they have a body and reveal biological phenomena like other animals.

Non-intentional Causality

The experimental evidence presented so far enables us to indicate that young children have a coherently organized body of knowledge applicable to living things. This body of knowledge can be called a theory only when a causal explanatory framework is included in it. This concerns the third component of their biological knowledge. Here the type of causality, intentional or non-intentional, determines the nature of a theory. Carey (1985) claimed that, as mentioned above, children before age 10

base their explanations of biological phenomena on an intentional causality, because they are ignorant of physiological mechanisms involved. On the contrary, we claim that young children before schooling can apply a non-intentional causality in explaining biological phenomena, and thus they have a form of biology which is differentiated from psychology.

Young children cannot give articulated mechanical explanations when asked to explain biological phenomena (e.g., bodily processes mediating input-output relations) in an open-ended interview (e.g., Gellert, 1962); sometimes they try to explain them using the language of person-intentional causality (Carey, 1985). These findings apparently support the claim that young children do not yet have biology as an autonomous domain. It seems inevitable to accept this claim so long as we assume only two types of causalities, i.e., intentional causality versus mechanical causality, as represented by Carey (1985). However, we propose an intermediate form of causality between these two. Children may not be willing to use intentional causality for biological phenomena but not as yet able to use mechanical causality. These children may rely on this intermediate form of causality, which might be called "vitalistic causality."

Intentional causality means that a person's intention causes the target phenomenon, whereas mechanical causality means that physiological mechanisms cause the target phenomenon. For instance, a specific bodily system enables a person, irrespective of his or her intention, to exchange substances with its environment or to carry them to and from bodily parts. In contrast, vitalistic causality indicates that the target phenomenon is caused by activity of an internal organ, which has, like a living thing, "agency" (i.e., a tendency to initiate and sustain behaviors). The activity is often described as a transmission or exchange of the "vital force," which can be conceptualized as unspecified substance, energy, or information. Vitalistic causality is clearly different from person-intentional causality in the sense that the organ's activities inducing the phenomenon are independent of the intention of the person who possesses the organ.

In Inagaki and Hatano (1990) some of the children of ages 5-8 gave explanations referring to something like vital force as a mediator when given novel questions about bodily processes, such as, what the halt of blood circulation would cause; for example, one child said, "If blood does not come to the hands, they will die, because the blood does not carry energies to them," and another child, "We wouldn't be able to move our hands, because energies fade away if blood does not come there." However, as the number of these children was small, we did another experiment to induce children to choose a plausible explanation out of the presented ones.

Inagaki and Hatano (1993, Experiment 2) predicted that even if young children could not apply mechanical causality, and if they could not generate vitalistic causal explanations for themselves, they would prefer vitalistic explanations to intentional ones for bodily processes when asked to choose one from among several possibilities. We asked 6-year-olds, 8-year-olds, and college students as subjects to choose one from three possible explanations each for six biological phenomena, such as blood circulation and breathing. The three explanations represented intentional, vitalistic and mechanical causality, respectively.

An example question on blood circulation with three alternative explanations was as follows: Why do we take in air? (a) Because we want to feel good [intentional]; (b) Because our chest takes in vital power from the air [vitalistic]; (c) Because the lungs take in oxygen and change it into useless carbon dioxide [mechanical].

As shown in Figure 4, the 6-year-olds chose vitalistic explanations as most plausible most often; they chose them 54% of the time. With increasing age the subjects came to choose mechanical explanations most often. It should be noted that the 6-year-olds applied non-intentional (vitalistic plus mechanical) causalities 75% of the time, though they were more apt to adopt intentional causality than the 8-year-olds or adults.

This vitalistic causality is probably derived from a general mechanism of personification. One who has no means for observing the opaque inside or details of the target object often tries to understand it in a global fashion, by assuming it or its components to be human-like (Ohmori, 1985). Hence, young children try to understand the workings of internal bodily organs by regarding them as human-like (but non-communicative) agents, and by assigning their activities global life-sustaining characters, which results in vitalistic causality for bodily processes. We can see a similar mode of explanation in the Japanese endogenous science before the Meiji restoration (and the beginning of her rapid modernization), which had evolved with medicine and agriculture as its core (Hatano & Inagaki, 1987).

Young children seem to rely on vitalistic causality only for biological phenomena. They seldom attribute social-psychological behavior, which is optional and not needed for survival, to the agency of a bodily organ or part, as revealed by Inagaki and Hatano (1993, Experiments 3 and 3a). The following is an example question for such behavior used in the study: "When a pretty girl entered the room, Taro came near her. Why did he do so?" Eighty percent of the 6-year-olds chose, "Because Taro wanted to become a friend of hers" [intentional explanation], whereas only 20 percent opted for, "Because Taro's heart urged him to go near her" [vitalistic]. For biological phenomenon questions, almost the same as those used in Experiment 2 of Inagaki and Hatano (1993) except for excluding the mechanical causal explanation, they tended to choose vitalistic explanations rather than intentional ones.

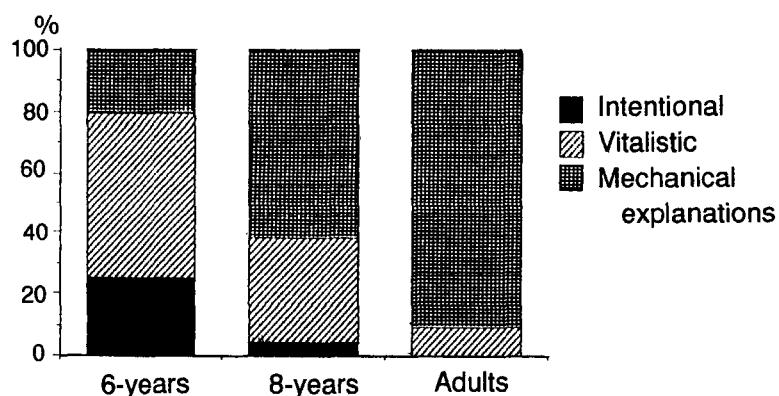


FIGURE 4 Percentages of choices for different types of causal explanations.

Then, two theoretical issues emerge. First, does the use of vitalistic causality by young children falsify Carey's claim? It does not do so necessarily. We do not know yet which of human properties, in addition to "agency", children assign to bodily organs. It is possible that children, especially younger ones, find organ-intentional vitalistic explanations appealing for biological phenomena. If this is the case, we must conclude that young children's biology is still "psychological" in the sense that it involves intentional states, though the domain is differentiated from psychology. Second, what is the relationship between the vitalistic explanation for biological phenomena and the teleological-functional explanation for biological properties (Keil, 1992)? Both are certainly in-between the intentional and the mechanical; both seem to afford valid perspectives of the biological world. One interpretation is that they are essentially the same idea with different emphases—the teleological concerns more the why or the cause, whereas the vitalistic is concerned more with the how or the process. Another interpretation is that, because the vitalistic explanation refers to activity of the responsible organ or bodily part (implicitly for sustaining life), it is closer to mechanical causality than is the teleological one, which refers only to the necessity. Anyway, it will be intriguing to examine these characterizations of young children's "biological" explanations in concrete experimental studies.

Young Children Possess a Naïve Theory of Biology

From the above findings we can conlude that children as young as 6 years of age possess three essential components of biology, that is, the living-nonliving and the mind-body distinctions, a mode of inference enabling one to produce consistent and reasonable predictions for animate objects, and a non-intentional causal explanatory framework. These components correspond respectively to the three features that Wellman (1990) lists in characterizing framework theories: ontological distinctions, coherence, and a causal-explanatory framework. We can conclude that, contrary to Carey (1985), children before schooling have acquired a form of biology differentiated from psychology.

Use, Acquisition and Change of Naïve Biology

How Naïve Biology is Used

The components of young children's biology, which are described in the preceding section, have been identified through interviews, more specifically, based on children's answers to experimental questions regarding biological phenomena. In this sense their naïve biology is psychologically real. However, some skeptical readers may wonder if such answers are generated by strange experimental questions, and if children almost never use such "biological knowledge" in their everyday life. In order to persuade those readers, we will discuss in this section (1) whether naïve biology is relied on in children's everyday problem solving and understanding, and (2) whether it enhances children's learning and memory about animals and plants.

Children's use of naïve biology in their daily life. Although we have not yet examined systematically a database of young children's utterances, a few observant early educators have reported instances revealing that naïve biology enables young chil-

dren to make sense of biological phenomena they observe, and also to solve daily problems involving animals and plants. For example, Motoyoshi (1979) reports the following statement of a 5-year-old girl. Based on accumulated experience with raising flowers, and relying on her naive biology, she concluded: "Flowers are like people. If flowers eat nothing (are not watered), they will fall down of hunger. If they eat too much (are watered too often), they will be taken ill". This superb analogy demonstrates that young children's personifying biology can serve as the basis for understanding botanical phenomena and thus constitute what Keil (1992) calls a mode of construal.

Likewise, we believe that young children's biology is useful in everyday biological problem solving, more specifically, in (a) making predictions for reactions of familiar animate entities to novel situations, (b) finding a cause for an unusual reaction of animals and plants, and (c) predicting properties and behaviors of unfamiliar entities. An anecdotal but impressive example of causal attribution for an animal's unusual physical reaction is reported also by Motoyoshi (1979). Children aged 5 in a day care center inferred that, when they observed unusual excretion of a rabbit they were taking care of every day, it might be suffering from diarrhea like a person, and after group discussion, they produced an idea of making the rabbit take medicine for diarrhea as a suffering person would.

Hatano and Inagaki (1991b) examined experimentally whether young children would make causal reasoning based on their personifying biology, as suggested in the above example. They presented to 6-year-olds three bodily phenomena of a squirrel, which can also be observed for humans (being constipated, diarrhea, and getting older and weaker), and asked them to guess a cause for each phenomenon. About three quarters of them on the average could offer some reasonable causes, and also judge the plausibility of causes suggested by the experimenter. About a half of them explicitly referred to humans at least once in their causal attributions for a squirrel. At the same time, however, some of their expressions strongly suggest that they edited or adapted to this animal those responses obtained by the person analogy (e.g., "A squirrel became weaker because it did not eat chestnuts"). Naive biology seems to provide young children with a conceptual tool for causal reasoning about bodily phenomena of other animals as well as humans.

Naive biology as prior knowledge for learning about animals and plants. We expect that young children promptly remember those facts concerning animals and plants which are plausible within their naive biological framework. In our experiment in progress, we presented 5- and 6-year-olds one of the two lists, connected or random, and asked to remember sentences in it. Each sentence consisted of an unfamiliar animal as the subject, its behavior, and outcome. In the connected list, the behavior and the outcome were causally connected in naive biology, because the cause induces the outcome in humans (e.g., "A coyote ate rotten meat and had diarrhea"). In the random list, causes and outcomes were randomly paired. The data are being analyzed, but we expect to find that young children would recall sentences in the connected list much better, even when sentences were false for those animals.

Naive biology is particularly useful because it helps children learn meaningfully

procedures for taking care of animals and plants as well as themselves in everyday life. Global understanding of internal bodily functions is enough for such purposes. Inagaki and Kasetani (1994) examined whether inducing the person analogy, a critical component of naive biological knowledge, would enhance 5- and 6-year-olds' comprehension of raising procedures of a squirrel. The subjects were aurally given the description of the procedures while watching pictures visualizing them. The description included several references to humans in the experimental condition but not in the control condition. For example, about the necessity of giving a variety of food to a squirrel, the experimenter indicated, "You do not eat favorite food only. You eat a variety of food, don't you?" After listening to the description of all procedures, the children were asked to tell how to raise a squirrel to another lady (a confederate). They were asked questions by this lady, e.g., "What kind of food might I give a squirrel? Favorite chestnuts only, chestnuts, seeds and vegetables mixed, or ice cream?" They were thus required to choose an alternative and to give the reason.

The experimental group children, irrespective of age, gave more often adequate reasons for their correct choices than the control ones, though their superiority in the number of correct choices was significant only for the younger subjects. For instance, one 5-year-old child said, "Don't feed chestnuts only. You must give a squirrel a plenty of seeds and carrots, because a person will die if he eats the same kind of food only, and so will it."

There have also been studies suggesting that children can find how to solve a problem by being given some hints to use knowledge about humans when they are at a loss. In Inagaki and Hatano's (1987) study on analogy mentioned above, children who had no idea about reactions of the target objects in novel situations were given a hint, such as, "If you were in that situation, what would you do?" After making a response to this inserted question, they were again asked the same question about the target object. This hint question helped about 80% of the children produce some predictions for the target objects, and about 70% of their predictions were reasonable.

A similar example of the effect of such a hint is found in a teacher's guidebook made by a Japanese Research and Development group called the "*Kyokuchi*" method in science education (1974). In the unit on animals' bodily structures and their ways of living children are given the following problem: "Which is a bigger eater, a starfish or sea anemone?" By being given a hint, such as "Taking exercise makes you hungry, doesn't it?", they are likely to figure out the correct choice successfully.

What triggers biological knowledge. Young children's naive biology is functional partly because its components are promptly and effortlessly retrieved and used to generate more or less plausible ideas. Their personifying and vitalistic biology seems to be triggered almost automatically whenever children come into contact with novel phenomena which they recognize as "biological" (Inagaki, 1990b). Then, what phenomena are recognized by children as biological? Those occurring within a (human) body are almost always treated as biological. In addition, behaviors and properties which are relevant to survival (and also reproduction) seem to trigger children's biological knowledge. For example, in experiments by Vera and Keil (1988) those contexts referring to a person's living better or becoming more active produced more extended and accu-

rate induction of human biological properties to animals, whereas those indicating a person's subjective feelings did not. In Inagaki and Hatano's (1994) experiment contexts referring to the vital force produced induction extended even to plants.

Speaking generally, making an educated guess by applying insufficient knowledge is often rewarded in everyday life, both in individual problem solving and in social interaction, so most everyday knowledge is readily used. Children's naive biology is not an exception, we believe. In fact in our study described above (Inagaki & Hatano, 1987) it was very rare that the children gave no prediction or the "I don't know" answer to our questions which were somewhat unusual. It should also be noted that naive biological knowledge is seldom applied "mechanically." As mentioned earlier, children constrain their analogies by factual, procedural or conceptual knowledge about the target to generate a reasonable answer.

Acquisition of Naive Biology

As already mentioned, our experimental data strongly suggest that children as young as 6 years of age have acquired a form of biology. This early acquisition of biology is not surprising from the perspective of human evolution, because it has been essential for our species to have some knowledge about animals and plants as potential foods (Wellman & Gelman, 1992) and also knowledge about our bodily functions and health (Hatano, 1989; Inagaki & Hatano, 1993). When children acquire an autonomous domain of biology is still an open question for us, because we have not examined whether much younger subjects too possess a form of biology.

However, we think that the acquisition of biology comes a little later than that of physics or psychology. Infants seldom need biological knowledge, since they do not need to take care of their health nor try to find food themselves. Moreover, autonomous biology has to deal with entities which have agency (i. e., initiate and maintain activity without external forces) but can hardly communicate with us humans, and thus has to apply an intermediate form of causality between the intentional and mechanical. Autonomous biology also requires to include animals and plants, which appear so different, into an integrated category of living things. Though there is some evidence that even infants can distinguish objects having a capacity for self-initiated movement from those not having it (e. g., Golinkoff, Harding, Carlson, & Sexton, 1984), this cannot directly serve as the basis for the living-nonliving distinction.

Cognitive bases of naive biology. Whether naive biology gradually emerges out of naive psychology (Carey, 1985) or is a distinct theory or mode of construal from the start (Keil, 1992) is still debatable. It is true that, as Keil argues, preschool children have some understanding of the distinction between the biological and the social-psychological (See above). In Vera and Keil (1988), for example, 4-year-olds' inductions about animals, when given the biological context, resembled those previously found for 7-year-olds, who were given the same attribution questions without context ; giving the social-psychological context to 4-year-olds did not affect the inductions they made. However, young children may overestimate the controllability of bodily processes by will or intention. In fact, our modified replication study on the controllability of internal bodily functions suggests that 3-year-olds are not sure whether the workings of

bodily organs are beyond their control (Inagaki & Suzuki, 1991).

Our own speculation about how young children acquire personifying and vitalistic biology through everyday life experiences is as follows. Children notice through somatosensation that several "events", uncontrolled by their intention, are going on inside the body. Since children cannot see the inside of the body, they will try to achieve "global understanding" by personifying an organ or bodily part. Considering that young children use analogies in a selective, constrained way (Inagaki & Hatano, 1987, 1991; Vosniadou, 1989), it is plausible that they apply the person analogy to bodily organs in that way, too. More specifically, they attribute agency and some related human properties but not others (e.g., the ability to communicate) to these organs. They also through personification generalize this global understanding of the body to other living things.

A set of specific innate or very early cognitive constraints is probably another important factor in the acquisition of naive biology. It is likely that even very young children have tendencies to attribute a specific physical reaction to a specific class of events, such as that diarrhea is caused by eating something poisonous. These tendencies enhance not only their rejection of intentional causality for bodily phenomena but also their construction of more specific beliefs about bodily processes.

Universals in naive biology. That innate constraints serve as the bases for acquiring naive biology has been strongly suggested by the universality of selected aspects of folkbiology and naive biology. As suggested by Atran (1990), it may be possible to find the "common sense" or core beliefs shared by all forms of folkbiology and even by scientific biology. Although what are such core beliefs is debatable, the taxonomy of animate entities or a set of the ontological distinctions is certainly included among them, because all folkbiological classifications reported so far correspond to the scientific one highly accurately (e.g., Boster, 1991).

Likewise, much of the research inspired by Piaget, e.g., those examining children's attribution of life status and consciousness to a variety of objects, has shown parallels among the biological understanding or naive biology of children in different cultures. The distinctions between animals and terrestrial inanimate objects are particularly strong. The frequent use of personification and reliance on vitalistic causality, important components of naive biology, are also expected to be more or less universal, though they have been documented only in a few countries.

Activity-based experiences. We are willing to admit that, because of the above general mechanism of personification and the resultant vitalistic causality, which "fit nicely with biology" (Keil, 1992, p. 105), and specific cognitive constraints, there must be some core elements in naive biology that are shared among individuals within and between cultures, as suggested by Atran (1990). However, we would like to emphasize that this does not mean children's activity-based experiences do not contribute to the acquisition. Some such experiences are also universal in human ways of living, but others may vary and thus produce differently instantiated versions of naive biology. For example, if children are actively engaged in raising animals, it will be possible for them to acquire a rich body of knowledge about them, and therefore to use that body of knowledge, as well as their knowledge about humans, as a source for analogical

predictions and explanations for other biological kinds.

Our studies have in fact revealed that such an activity may produce a slightly different version of naive biology from the ordinary one. Inagaki (1990a) compared the biological knowledge of kindergarteners who had actively engaged in raising goldfish for an extended period at home with that of the children of the same age who had never raised any animal. Although these two groups of children did not differ in factual knowledge about typical animals in general, the goldfish-raisers had much richer procedural, factual, and conceptual knowledge about goldfish. More interestingly, the goldfish-raisers used the knowledge about goldfish as a source for analogies in predicting reactions of an unfamiliar "aquatic" animal (i.e., a frog), one that they had never raised, and produced reasonable predictions with some explanations for it. For example, one of the raisers answered when asked whether we could keep a baby frog in the same size forever, "No, we can't, because a frog will grow bigger as goldfish grew bigger. My goldfish were small before, but now they are big." It might be added that the goldfish-raisers tended to use person analogies as well as goldfish analogies for a frog. In other words, the goldfish-raisers could use two sources for making analogical predictions.

Moreover, in another study (Kondo & Inagaki, 1991; See also Hatano & Inagaki, 1992), goldfish-raising children tended to enlarge their previously possessed narrow conception of animals. As shown in Figure 5 as an example, Goldfish-raisers attributed animal properties which are shared by humans (e.g., having a heart, excreting, etc.) not only to goldfish but also to a majority of animals phylogenetically in between humans and goldfish at a higher rate than non-raisers. This suggests that the experience of raising goldfish modifies young children's preferred mode of biological inferences.

Cultural and linguistic variables. The biological understanding observed in different cultures is not identical. The most striking of the differences thus far reported concerns ideas about plants of children in Israel. Stavy and Wax (1989) showed that about a half of a sample of 6-12 year-olds, when asked to judge the life status of animals, plants, and nonliving things, classified plants either as nonliving things or as falling within a third category, things that are neither living nor nonliving. Beliefs about inanimate objects also may differ between cultures. Whereas recent studies conducted in North America indicate that young children seldom attribute life or other living thing properties to any terrestrial inanimate objects (e.g., Dolgin & Behrend, 1984; Richards & Segler, 1984), Inagaki and Sugiyama (1988) reported that some Japanese preschoolers extended mental properties even to inanimate objects without movement or function, such as stones.

Hatano, Siegler, Richards, Inagaki, Stavy and Wax (1993) tried to differentiate between universal and culturally specific aspects of children's conceptions of life and understanding of attributes of living things, by comparing kindergarteners, 2nd-, and 4th-graders from Israel, Japan and the United States. The children were asked whether two instances each of four object types (people, other animals, plants and inanimate objects) possessed each of 16 attributes that included life status (being alive), unobservable animal attributes (e.g., has a heart), sensory attributes (e.g., feels pain), and

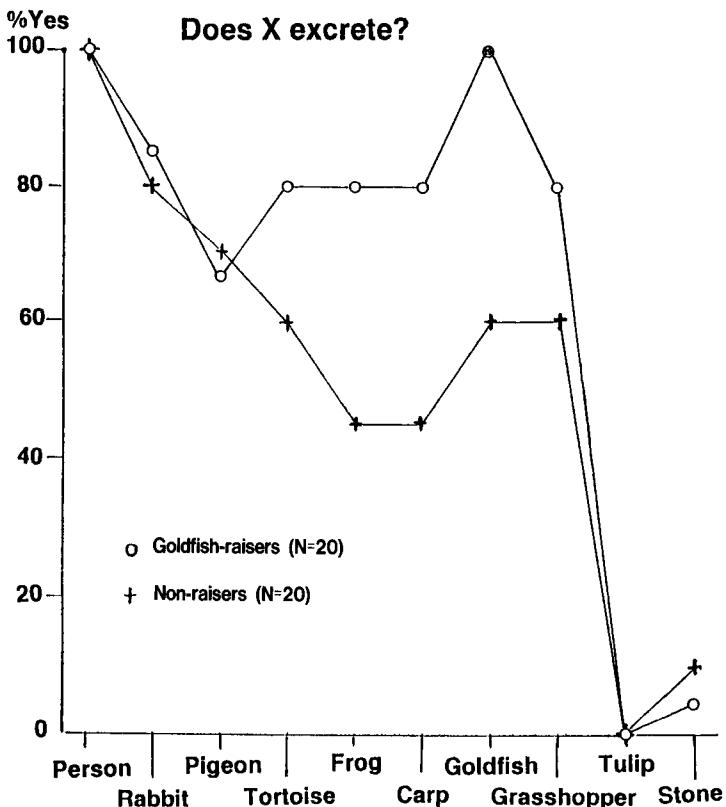


FIGURE 5 Attributional patterns of excretion to varied objects in goldfish-raising and non-raising children.

attributes true of all living things (e.g., grows bigger).

The results illustrate both similarities and differences across cultures in children's biological understanding. Children in all cultures knew that people, other animals, plants, and inanimate objects were different types of entities, with different properties, and were extremely accurate regarding humans, somewhat less accurate regarding other animals and inanimate objects, and least accurate regarding plants. At the same time, as predicted from cultural analyses, Israeli children were considerably more likely not to attribute to plants properties that are shared by all living things, whereas Japanese children, whose overall accuracy was comparable to the Israeli, were considerably more likely to attribute to inanimate objects properties that are unique to living things.

These differences are especially interesting because they suggest that children's naive biology is influenced by beliefs within the culture where they grow up. Consider why Japanese children might be more likely than children in the U.S. or Israel to view plants or inanimate objects as alive and having attributes of living things. Japanese culture includes a belief that plants are much like human beings. This attitude is represented by the Buddhist idea that even a tree or blade of grass has a mind. In Japanese folkpsychology, even inanimate objects are sometimes considered to have

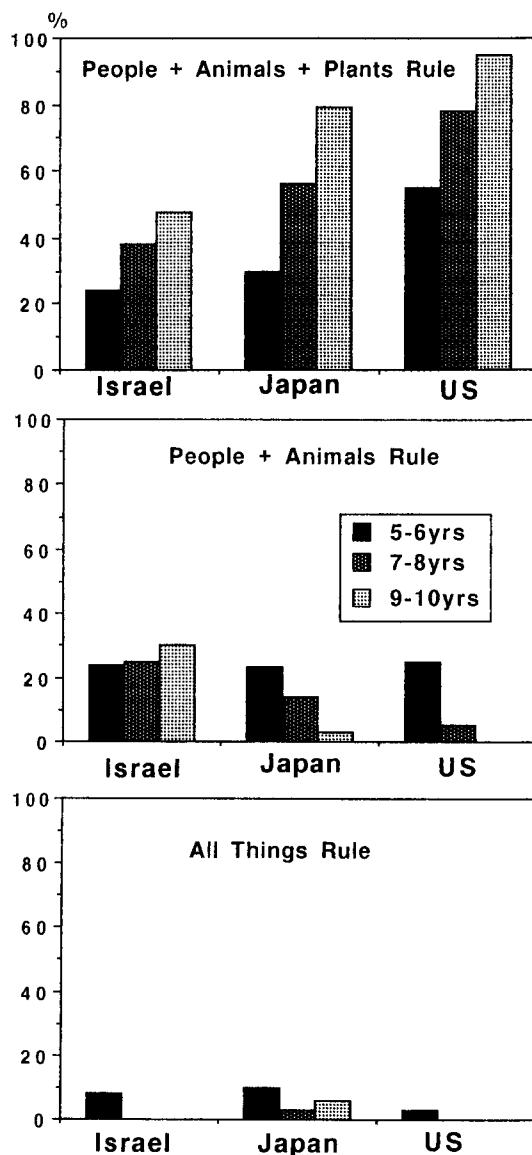


FIGURE 6 Percentages of children who adopted "people, animals and plants rule," "people and animals rule" and "all things rule."

minds. For example, it is at least not a silly idea for Japanese to assign life or divinity not only to plants but also to inanimate objects, especially big or old ones. In addition, linguistic factors seem to influence Japanese children's attributional judgments. The *kanji* (Chinese character) representing it has a prototypal meaning of "fresh" or "perishable" as well as "alive." Therefore, this *kanji* can be applied to cake, wine, sauce, and other perishable goods.

Similar features of culture and language may account for Israeli children being less apt than American or Japanese children to attribute to plants life status and prop-

erties of living things (See Figure 6). Stavy and Wax (1989) suggested that within the Israeli culture, plants are regarded as very different from humans and other animals in their life status. This cultural attitude parallels that of a Biblical passage (*Genesis*, 1, 30), well known to Israeli students, indicating that plants were created as food for living things including animals, bird, and insects. Adding to, or perhaps reflecting, their cultural beliefs, the Hebrew word for "animal" is very close to that for "living" and "alive." In contrast, the word for "plant" has no obvious relation to such terms.

How culture influences the development of biological understanding has yet to be studied. Parents, schools, and mass media may serve to transmit cultural beliefs. For example, Japanese parents may communicate the attitude through their actions toward plants and divine inanimate objects, though they do not usually tell their children this explicitly. Culture may provide children with opportunities to engage in activities that lead them to construct some particular biological understanding, as in the case of children of raising goldfish (Inagaki, 1990a; Hatano & Inagaki, 1992).

Evolution into Intuitive Biology

So far we have emphasized strengths of young children's naive biology. Doesn't it have any weaknesses? Of course, it does. Its weaknesses are obvious even when compared with intuitive biology that lay adults have, which is considered as a product of interaction between naive biology and so-called scientific biology. Let us list some major weaknesses of naive biology: (a) limited factual knowledge, (b) lack of inferences based on complex, hierarchically organized biological categories, (c) lack of mechanical causality, and (d) lack of some conceptual devices (e.g., "evolution," "photosynthesis").

As children grow older, they acquire more and more pieces of biological knowledge (elimination of the weakness a), and with it the status of humans changes. Young children regard humans as unique, and thus as a prototypical species of all living things, whereas older children and adults consider them as a very special species and as only a kind of animals.

As children grow older, their personifying and vitalistic biology gradually changes toward truly "non-psychological" (if not scientific) biology by eliminating the above weaknesses (b) and (c), namely, toward a biology which relies on category-based inferences and rejects intentional causal explanations. We assume that this change (or the fundamental restructuring of knowledge) is almost universal, at least among children growing up in highly technological societies, and that it can occur without systematic instruction in biology, though schooling may have some general facilitative effects on it. Acquisition of basic conceptual devices (elimination of the weakness d) seems to be difficult to be achieved without being taught so-called scientific biology at school, and incorporating them meaningfully into children's existing body of knowledge can usually be achieved only with the restructuring of that knowledge.

Let us present a few relevant empirical studies. Johnson, Mervis and Boster (1992) found that, whereas 10-year-olds and adults possess a category of primates and include a human in it, 7-year-olds regard a human very different even from a monkey.

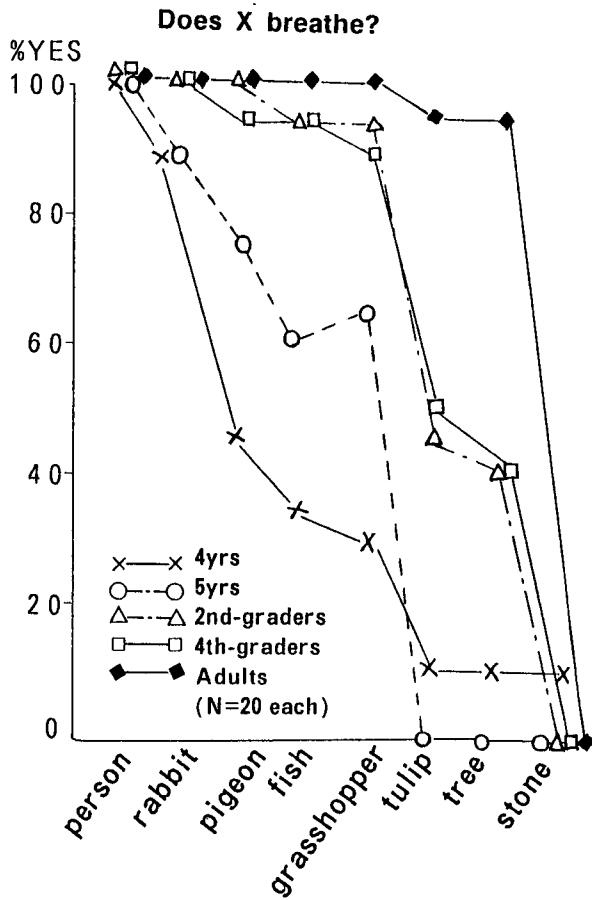


FIGURE 7 Attributive patterns of breathing to varied objects in each age group.

Carey (1985) also reported similar results, using the induction paradigm; when 4-year-olds were taught some novel properties on people, they attributed them to other animals to much greater than when taught on dogs. In contrast, 10-year-olds and adults who were taught on dogs were hardly distinguishable in attributional patterns from those taught on people. Rather, projections from dogs were slightly greater than from people. These results indicate that the status of humans changes from that of a prototype to what is not more prototypical than dogs.

Inagaki and Sugiyama (1988) examined how young children's human-centered or "similarity-based" inference would change as they grew older. They gave attribution questions, such as "Does X have a property Y?", to children aged 4 to 10 and college students. Results indicated that there was a progression from 4-year-olds' predominant reliance on similarity-based attribution (attributing human properties in proportion to perceived similarity between target objects and humans) to adults' predominant reliance on category-based attribution (attributing by relying on the higher-order category membership of the targets and category-attribute associations). Figure 7 shows an example of developmental patterns obtained in the attribution of anatomical/physiologi-

cal properties.

This shift from similarity-based to category-based inferences is induced not only by an increased amount of knowledge but also by the development of metacognitive beliefs evaluating more highly the usefulness of higher-order categories (Inagaki, 1989). Children realize that higher-order categories are more dependable than the similarities for making correct predictions. Higher-order categories are very helpful in predicting unfamiliar animals' behaviors, attributes, habitats, and so on. This realization facilitates the use of such categories in any situation in which a biological inference is required. Hatano and Inagaki (1991a) provided data to confirm this idea, using a task designed to assess children's metacognitive beliefs about the dependability of category-based versus similarity-based inference.

As children grow older, there also occurs a developmental change in causality for internal bodily functions. In contrast to young children's vitalistic, and sometimes even intentional, biological explanations, older children reject intentional explanations for biological phenomena and are inclined to use mechanical causality exclusively. In Experiment 2 of Inagaki and Hatano's (1993) study, the difference between 6-year-olds and 8-year-olds was larger than the difference between 8-year-olds and adults in terms of preference for mechanical explanations and avoidance of intentional ones (See Figure 4).

These results suggest that young children's biology is qualitatively different from the biology that older children and adults have, and that, in accordance with Carey's claim, there occurs a conceptual change in biological understanding between ages 4 and 10. However, contrary to her claim, this change is characterized not as the differentiation of biology from psychology but as a qualitative change within the autonomous domain of biology, because children as young as 6 years of age already possess a form of biology.

Another important change may occur as a result of the learning of scientific biology at school, which is often beyond intuitive biology. In order to be able to reason "scientifically" in biology one needs to know its basic concepts and principles, major conceptual devices which cannot be acquired without intervention. For example, if one does not know the phenomenon of photosynthesis, one will not be able to understand the difference between animals and plants (i.e., plants can produce nutrient themselves), and thus may accept the false analogy of mapping water for plants with food for animals. We assume that, unlike the first conceptual change just described above, this change is hard to achieve and thus occurs only among a limited portion of older children or adolescents.

Is adults' intuitive biology no more personifying? Does the intuitive biology no more rely on vitalistic biology? Answers for these questions are No. The fact that there exists a shift from similarity-based to category-based inferences does not mean that older children and adults never rely on the similarity to people in their attributions. Inagaki and Sugiyama (1988) reported that a substantial number of adults as well as older children still rely on similarity to people in attributing mental properties to varied animate entities. Morita, Inagaki and Hatano (1988), using reaction time measures, revealed that college students use the similarity to people to some extent not only for

mental properties but also anatomical/physiological ones in a situation in which they have to respond very quickly and thus are not able to use the category membership of target objects and category-property relationships. These results strongly suggest that personification or the person analogy may be used even by adults as a fallback strategy.

The fact that college students preferred much more strongly mechanical causality to the vitalistic one (Inagaki & Hatano, 1993, Experiment 2) does not mean that they never rely on the latter in any situation. One of the college students in Inagaki and Hatano (1993) consistently chose vitalistic explanations, and answered for an inquiry at the interview after experiment, "We usually choose those including 'oxygen' or 'the heart works like a pump' because we have learned in school to do so. However, I chose others because they were most convincing and comprehensible to me." This suggests that vitalistic biology continues to work as a basis of understanding and to be used in situations where people do not think that they are required to answer based on so-called scientific biology.

Conclusions

Since Carey (1985), young children's naive biology has been an exciting topic for research in cognitive development. As more and more ambitious researchers have joined to study it, a richer database has been built and finer conceptualizations offered about this specific issue. It will probably be a popular topic for the coming several years, and research questions about naive biology, like the ones discussed so far in this article, can be better answered and/or better rephrased.

REFERENCES

- Atran, S. (1990). *Cognitive foundations of natural history: Towards an anthropology of science*. Cambridge: Cambridge University Press.
- Backscheider, A. G., Shatz, M. & Gelman, S. A. (1993). Preschoolers' ability to distinguish living kinds as a function of regrowth. *Child Development*, **64**, 1242-1257.
- Boster, J. S. (1991). The information economy model applied to biological similarity judgment. In L. B. Resnick, J. M. Levine, & S. D. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 203-225). Washington, D.C.: American Psychological Association.
- Carey, S. (1985). *Conceptual change in childhood*. Cambridge, MA: MIT Press.
- Dolgin, K. G. & Behrend, D. A. (1984). Children's knowledge about animates and inanimates. *Child Development*, **55**, 1646-1650.
- Gellert, E. (1962). Children's conceptions of the content and functions of the human body. *Genetic Psychology Monographs*, **65**, 291-411.
- Gelman, R. (1990). First principles organize attention to and learning about relevant data: Number and the animate-inanimate distinction as examples. *Cognitive Science*, **14**, 79-106.
- Gelman, R., Spelke, E. & Meck, E. (1983). What preschoolers know about animate and inanimate objects. In D. Rogers and J. A. Sloboda (Eds.), *The acquisition of symbolic skills* (pp. 297-326). New York: Plenum.
- Golinkoff, R. M., Harding, C. G., Carlson, V., & Sexton, M. E. (1984). The infant's perception of causal events: the distinction between animate and inanimate objects. In L. P. Lipsitt & C. Rovee-Collier (Eds.), *Advances in Infancy Research*, (vol. 3, pp. 145-165). Norwood, NJ: Ablex.
- Hatano, G. (1989). Language is not the only universal knowledge system: A view from "everyday

- cognition." *Dokkyo Studies in Data Processing and Computer Science*, 7, 69-76.
- Hatano, G. & Inagaki, K. (1987). Everyday biology and school biology: How do they interact? *The Quarterly Newsletter of the Laboratory of Comparative Human Cognition*, 9, 120-128.
- Hatano, G. & Inagaki, K. (1991a). *Learning to trust higher-order categories in biology instruction*. Paper presented at the meeting of the American Educational Research Association, Chicago.
- Hatano, G. & Inagaki, K. (1991b). *Young children's causal reasoning through spontaneous personification*. Paper presented at the 33rd annual convention of the Japanese Association of Educational Psychology, Nagano. [in Japanese].
- Hatano, G. & Inagaki, K. (1992). Desituating cognition through the construction of conceptual knowledge. In P. Light & G. Butterworth (Eds.), *Context and cognition: Ways of learning and knowing* (pp. 115-133). London: Harvester/Wheatsheaf.
- Hatano, G. & Inagaki, K. (1994). *Recognizing commonalities between animals and plants*. Paper to be presented at the meeting of the American Educational Research Association, New Orleans.
- Hatano, G., Siegler, R. S., Richards, D. D., Inagaki, K., Stavy, R., & Wax, N. (1993). The development of biological knowledge: A multi-national study. *Cognitive Development*, 8, 47-62.
- Inagaki, K. (1989). Developmental shift in biological inference processes: From similarity-based to category-based attribution. *Human Development*, 32, 79-87.
- Inagaki, K. (1990a). The effects of raising animals on children's biological knowledge. *British Journal of Developmental Psychology*, 8, 119-129.
- Inagaki, K. (1990b). Young children's use of knowledge in everyday biology. *British Journal of Developmental Psychology*, 8, 281-288.
- Inagaki, K. (1993a). *Young children's differentiation of plants from nonliving things in terms of growth*. Paper presented at the biennial meeting of the Society for Research in Child Development, New Orleans.
- Inagaki, K. (1993b). *The nature of young children's naive biology*. Paper presented at the symposium, "Children's naive theories of the world," at the 12th meeting of the International Society for the Study of Behavioral Development, Recife, Brazil.
- Inagaki, K. & Hatano, G. (1987). Young children's spontaneous personification as analogy. *Child Development*, 58, 1013-1020.
- Inagaki, K. & Hatano, G. (1990). *Development of explanations for bodily functions*. Paper presented at the 32nd annual convention of the Japanese Association of Educational Psychology, Osaka. [in Japanese].
- Inagaki, K. & Hatano, G. (1991). Constrained person analogy in young children's biological inference. *Cognitive Development*, 6, 219-231.
- Inagaki, K. & Hatano, G. (1993). Young children's understanding of the mind-body distinction. *Child Development*, 64, 1534-1549.
- Inagaki, K. & Hatano, G. (1994). *Effects of biological contexts on children's induction of human properties*. Paper to be presented at the 36th annual convention of the Japanese Association of Educational Psychology, Kyoto, [in Japanese].
- Inagaki, K. & Kasetani, M. (1994). *Effects of hints to use knowledge about humans on young children's understanding of biological phenomena*. Paper to be presented at the 13th meeting of the International Society for the Study of Behavioral Development, Amsterdam.
- Inagaki, K. & Sugiyama, K. (1988). Attributing human characteristics: Developmental changes in over- and underattribution. *Cognitive Development*, 3, 55-70.
- Inagaki, K. & Suzuki, Y. (1991). *The understanding of the mind-body distinction in children aged 3 to 5 years*. Paper presented at the 33rd annual convention of the Japanese Association of Educational Psychology, Nagano. [in Japanese].
- Johnson, K. E., Mervis, C. B., & Boster, J. S. (1992). Developmental changes within the structure of

- the mammal domain. *Developmental Psychology*, **28**, 74-83.
- Keil, F. C. (1992). The origins of an autonomous biology. In M. R. Gunnar & M. Maratsos (Eds.), *Modularity and constraints in language and cognition: The Minnesota symposia on child psychology* (vol. 25, pp. 103-137). Hillsdale, NJ: Erlbaum.
- Kondo, H. & Inagaki, K. (1991). Effects of raising goldfish on the grasp of common characteristics of animals. Paper presented at the 44th meeting of the Japanese Association of Early Childhood Education and Care, Kobe. [in Japanese].
- Kuhn, D. (1989). Children and adults as intuitive scientists. *Psychological Review*, **96**, 674-689.
- Kyokuchi method in science education (1974). Unit on animals' bodily structures and their ways of living. Unpublished text. [in Japanese].
- Massey, C. M. & Gelman, R. (1988). Preschooler's ability to decide whether a photographed unfamiliar object can move itself. *Developmental Psychology*, **24**, 307-317.
- Morita, E., Inagaki, K. & Hatano, G. (1988). *The development of biological inferences: Analyses of RTs in children's attribution of human properties*. Paper presented at the 30th annual convention of the Japanese Association of Educational Psychology, Naruto. [in Japanese].
- Motoyoshi, M. (1979). *Essays on education for day care children: Emphasizing daily life activities*. Tokyo: Froebel-kan. [in Japanese].
- Ohmori, S. (1985). *The structure of knowledge and science*. Tokyo: Nihon Hoso Shuppan Kyokai. [in Japanese].
- Richards, D. D. & Siegler, R. S. (1984). The effects of task requirements on children's life judgments. *Child Development*, **55**, 1687-1696.
- Richards, D. D. & Siegler, R. S. (1986). Children's understandings of the attributes of life. *Journal of Experimental Child Psychology*, **42**, 1-22.
- Rosengren, K. S., Gelman, S. A., Kalish, C. W., & McCormick, M. (1991). As time goes by: Children's early understanding of growth. *Child Development*, **62**, 1302-1320.
- Siegal, M. (1988). Children's knowledge of contagion and contamination as causes of illness. *Child Development*, **59**, 1353-1359.
- Springer, K. & Keil, F. C. (1989). On the development of biologically specific beliefs: The case of inheritance. *Child Development*, **60**, 637-648.
- Springer, K. & Keil, F. C. (1991). Early differentiation of causal mechanisms appropriate to biological and nonbiological kinds. *Child Development*, **62**, 767-781.
- Stavy, R. & Wax, N. (1989). Children's conceptions of plants as living things. *Human Development*, **32**, 88-94.
- Vera, A. H. & Keil, F. C. (1988). *The development of inductions about biological kinds: The nature of the conceptual base*. Paper presented at the 29th meeting of the Psychonomic Society, Chicago.
- Vosniadou, S. (1989). Analogical reasoning as a mechanism in knowledge acquisition: A developmental perspective. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 413-469). Cambridge: Cambridge University Press.
- Wellman, H. M. (1990). *The child's theory of mind*. Cambridge, MA: MIT Press.
- Wellman, H. M., & Gelman, S. A. (1992). Cognitive development: Foundational theories of core domains. *Annual Review of Psychology*, **43**, 337-375.