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That's Life: Coming to Understand Biology

Essay Review on *Young Children's Thinking about the Biological World* by K. Inagaki and G. Hatano[1]

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Most people seem to live in worlds of the artificial. Those who are particularly inept with plants may awake in a home of devices and furniture, and when they work at home, encounter only machines and inanimate things. But even for the most urban and nature avoidant, biological thought is an essential part of daily life. We are after all inhabitants of biological systems and must confront that biology countless times in a day. When we feel hungry or thirsty, or tired, we are sensing biological systems and their consequences. When we perspire, or otherwise eliminate materials, we witness critical biological processes, as we do with every breath we take, with every blink of our eyes, and with every beat of our hearts. If we have a cold, or cut our finger, we witness a biological system under assault and its efforts to deal with any damage. Biology is therefore an inescapable part of all our lives.

The living world is a salient part of the world outside our bodies as well. Like their rural counterparts, most city dwellers routinely encounter plants and animals. More importantly, when an urban child first enters the countryside and is completely surrounded by living things, that child does not stagger around in miscomprehension. There may be some wonder at the richness and diversity, but not a feeling of being in an alien world. Yet, such shocks can occur when one encounters radically different cultures, or a different artificial world such as the floor of a specialized factory. Unfamiliar tools or devices can completely bring us up short. We can certainly encounter exotic animals and plants in far-off places, but most of their functions seem familiar. The living world comes easily and gracefully to us in ways that the artificial world often does not.

How it is that we come to understand the living world? Perhaps we are cognitively adapted from the start to understand the causal patterns and relations that are

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most common for living things. Or perhaps the living world reveals its patterns in such an obvious and compelling manner that they are mastered early on, often based on only small fragments experienced in urban environments. These are the central mysteries of folk biology and how it emerges in development. Kayoko Inagaki and Giyoo Hatano provide a superb analysis of this developmental story in their book *Young Children's Thinking about the Biological World.*

The Nature of Nature

Inagaki and Hatano discuss five reasons for studying the development of biological thought: (1) biology is a relevant concern for all children everywhere; (2) biological thought reveals both universal patterns of thought across cultures as well cross-cultural differences, far more so than naïve physics or naïve psychology; (3) biology may be the most relevant area to study the process by which we understand things through analogies to humans; (4) biology involves extensive categorization and illuminates one of the most basic aspects of cognition, and (5) naïve biology may reveal a particular kind of causal reasoning distinct from both the form used for physical mechanics and the form used for intentional behavior. These reasons illustrate how biology offers unique opportunities for the study of cognitive development. They also help highlight two questions about the uniqueness of biological phenomena and about the uniqueness of thoughts about those phenomena.

In what ways are biological phenomena distinct? Consider the perceptual level. While biological kinds tend to have typical sizes and shapes they also show variation not found in most modern manufactured objects. Biological kinds tend to have bilateral or radial symmetries (often related to locomotor and sensory systems), while nonliving natural kinds and artifacts vary considerably in degree and type of symmetry. Biological kinds are more rounded than rectilinear artifacts and have few sharp angles [Levin, Takarae, Miner, & Keil, 2001], and they tend to deform rather than break. Color variation is more restricted within most low-level biological categories than it is for most artifacts. Thus, a certain species of ants is likely to be all of the same color, while a certain kind of chair, such as a kitchen chair, may vary dramatically in color [Keil, Smith, Simons, & Levin, 1998].

Biological motion is also different from the artificial and nonliving natural worlds, be it in the patterns of locomotion of animals or in those swaying back and forth movements of bushes and trees [Cutting, 1986]. Moreover, the patterns of movement rarely conform to classical Newtonian mechanics. Animals move in decidedly irregular ways in comparison to the trajectories of simple bounded objects.

At the more conceptual level, living kinds are also distinct. The property of being small relative to other members of the same category (youth) is correlated with a longer future existence, not so for rocks or devices. The survival of living kinds often depends on close spatial and temporal proximity with other living kinds, again, not so for many artifacts.

Living things are inevitably distributed in taxonomic hierarchies, often of considerable depth [Atran, 1999]. Artifacts may also be in hierarchies, but these seem more arbitrary and are constructed and altered at whim. Biological kinds also grow, reproduce, respire, and share many molecular structures. Consider the list of things in common to tigers, snails, and jellyfish and compare them to the much smaller list of things in common to chairs, combs, and computers. The highest levels of biological kinds share far more properties than the highest levels of artifacts. Knowing a particular property of a living kind allows one to make very different, and usually more powerful, inductions than knowing a property of an artifact.

Finally, there are distinctive patterns of causation for living kinds [Keil, 1992]. For example, people weigh the first features in causal chains more heavily than later ones. Thus, in one study, novel animals called 'roobans' were said to eat fruits, have sticky feet, and build nests on trees. Participants were told that one feature tends to cause the second feature, which in turn tends to cause the third feature. The first element in the chain (eating fruits) was judged as more conceptually central to the category of roobans than the other features, even though they all occurred equally often in training examples. Moreover, when the causal relations were reversed for other subjects, the new feature in the first position in the causal chain became the central one. This 'causal status' bias highlights internal features as more critical for living kinds and external features for artifacts because internal causes tend to be seen as initial causes more often for living kinds while external features, such as a creator's intentions, are seen as more central for artifacts [Ahn, 1998; Ahn, Kim, Lassaline, & Dennis, 2000].

Another distinctive pattern of causation involves degree of causal interdependence. Most salient properties of living kinds are causally important to the integrity of that kind in ways not found for most artifacts. If a bird were a different color, a different shape, a different size, a different density, or a different material composition, all those differences are seen as causally relevant to whether it is the same kind of bird. For living kinds, there is a pattern of mutual dependence of features, or causal homeostasis [Keil, 1989; Boyd, 1999], that creates a stable entity because of the causal interplay of its parts. In contrast, a hammer is just as good a hammer regardless of its color, surface markings or even its internal composition as long as its functional properties are preserved. That artifact-based principle of function trumping other property changes is not at all applicable to living kinds.

The distinctive nature of biological phenomena does seem to have cognitive consequences. In both the philosophy of science [Sterelny & Griffiths, 1999; Hull & Ruse, 1998] and in cross-cultural studies, adults think about living kinds in ways that have distinctive characteristics. Thus, people envision stronger, more internal essences for living kinds [Gelman, 2003], tend to see living kinds as embedded in deep taxonomies [Atran, 1999], and reason about living kinds in teleological terms where properties are seen as having purposes that serve the living kind itself [Keil, 1992]. These patterns in adults naturally lead to questions of how distinctive patterns of thought about the living world might emerge in development. Inagaki and Hatano address these questions in great detail at both the empirical and the conceptual level. Their book shows how biological thought might emerge very early as a distinctive form of thought and how it then progresses to more mature forms. Moreover, while their analysis makes clear the special nature of biological thought and its development, it also reveals research strategies and theoretical considerations that have implications for many other domains as well.

Where Does Biological Thought Come from?

Building on their own extensive body of empirical work but also interweaving it with studies by others, Inagaki and Hatano provide an integrated analysis of the child's grasp of the living world and of the broader implications for the study of concepts and cognitive development. The cross-cultural perspective of their approach is especially useful. All too often, adult studies of an area may include substantial cross-cultural comparisons while the developmental versions may sit more solely within one culture.

Inagaki and Hatano make a strong case that a sense of a distinct living world emerges early. By five years of age, children know several properties shared by plants and animals. They both grow and take in food and water; and growth and taking in food and water are understood as related, suggesting a pattern of coherent beliefs, a hallmark of possessing a coherent theory instead of isolated 'facts'. Inagaki and Hatano speculate that an earlier emerging inanimate/animate distinction may help young children acquire the more sophisticated living/nonliving distinction; but the status of the animate/inanimate distinction as a form of biological thought is unclear. It is restricted to animals and might be a reflection of an early folk psychology; but it may also have components that are not simply beliefs about beliefs.

It is remarkable that the world of plants and animals comes to have a shared theoretical meaning for five-year-olds. The phenomenal chasm between the two seems so large that only a much more sophisticated biology could bridge it; yet the evidence clearly indicates a coherent understanding of living things. How do preschoolers come to this insight? Inagaki and Hatano suggest that the insight comes through two processes: personification and vitalism.

Because humans are so psychologically salient, we may neglect their usefulness for reasoning about biological processes. Some, such as Carey [1985], have taken young children's personification as evidence that they only think about biology in behavioral terms; but Inagaki and Hatano illustrate how appeals to human actions and processes can also indicate biological thought. They may sometimes be naïve and inappropriate applications of human processes to other living kinds but are biological thought nonetheless. For example, the idea of rest and nutrition leading to recovery from illness or trauma is extended from humans to animals and plants. Importantly, at the same age children will not freely extend behavioral/psychological properties from humans to animals and plants. Thus, a plant that accidentally is left behind by its owner is not assumed to engage in any actions that will get the owner to return or move it in closer proximity to its owner.

The other process leading to an early emerging biology is vitalism, which posits a vital force within living things that gives them not only life and health but also the impetus to grow, recover from illness and trauma, and possibly engage in reproduction. Inagaki and Hatano have brought vitalism to center stage in the study of biological thought and their extensive experimental studies reveal a distinctive form of reasoning. Vitalistic reasoning does not invoke any sort of mental notion and is thus not a proxy for a naïve psychology in which pseudo-biological notions are really about mental states. It is also different from mechanical causality and is not normally invoked for the nonliving world. If it is assumed that some crude versions of folk psychology and folk mechanics are bedrock primitives present even in infancy, vitalism must be shown to be distinct from both and not emerging out of either. Inagaki and Hatano do so clearly and convincingly.

Inagaki and Hatano consider mechanical causality both as physiological mechanisms and as simple physical mechanics (e.g., the action of teeth on food when chewing). Mechanistic reasoning in physiology, however, may not be the same as reasoning about the mechanical physics of bounded objects, which is normally the sort of naïve mechanics attributed to infants. This concern aside, it is impressive how often young children offer vitalistic explanations, and prefer them to other kinds of explanations such as the psychological and the mechanical. Inagaki and Hatano also describe a somewhat comparable preference for vitalistic explanations in Western children, an important point given the longer tradition of vitalistic explanations in adult folk biology in the East. A key remaining issue asks whether vitalism is displaced by mechanism when it is made available, especially of the physiological sort [cf. Au & Romo, 1996]. Thus, as the child gets older and understands more about physiology, vitalism might get sequestered to smaller and smaller sets of phenomena, perhaps eventually being eliminated altogether. Inagaki and Hatano suggest a more constant role for vitalistic thought throughout early development, with some remnants perhaps persisting into adulthood. Tracking the longer developmental course of vitalistic thought remains an important research project.

Inagaki and Hatano see vitalism as the initial core that may make folk biology domain specific right from the start. They also see teleological and essentialist thought as important to folk biology, but because neither is uniquely used in biology, those forms of reasoning are not seen as making the case for the distinctive nature of early biological thought. Teleology and essentialism, however, may contribute earlier on than is evident at first glance. Although young children will sometimes apply teleological reasoning to nonliving natural kinds as well as to artifacts [Keleman, 1999], they may also favor using such applications with living kinds [Opfer & Gelman, 2001]. Moreover, teleological reasoning may tend to be used in a different way with biology, focusing, for example, on more self-directed purposefulness. More broadly, how does one decide, when a particular kind of thought is heavily but not exclusively used in a domain, if it is evidence for that domain as having a distinctive kind of thought? This complex issue is highlighted more clearly in folk biology than in other domains, but has relevance for all discussions of domain specificity in development.

The same issues arise for essentialist biases. People can be seen to have behavioral and trait-like essences [Gelman, 2003; Hirschfeld, 1996]. For example, racist and sexist stereotypes often assume that groups have essential behavioral natures. Nonliving kinds, like gold, can also have essences and, by some accounts, artifacts may even have essences [Bloom, 1996]. Essentialist thought is therefore not unique to biology. It is, however, more dominant and easily used in biology, and it may tend to taint other domains with a biological flavor. For example, when people falsely essentialize racial traits, do they also tend to think of them in more biological terms? To fully understand the role of essentialist biases in demarcating the domain of biological thought will require a much more extensive tracking of how essentialist beliefs develop in different domains and how they influence each other.

Teleological and essentialist thought offer another model of how folk biology might become unique early on. A convergence of these modes of thought on living kinds may give biological thought its distinctive character. Even if essentialism and teleology are both used more broadly than living things, in combination their juxtaposition may make biology unique [Keil, 1992]. The rare use of teleology with nonliving natural kinds, which may also have essences, is a potential exception; but it is very uncommon to see the two ideas used together in a coherent way to apply to kinds such as gold.

Is vitalism that special cognitive ingredient that sets biological thought apart from the start or is a convergence of teleology and essentialism also important? All three may actually be interconnected. Vitalism often implies both an essence and an organism-centered functionality and purposiveness. My own hunch is that all three notions are intertwined in even the earliest aspects of biological thought and that the separation of any one component may be somewhat artificial. Only through this book, however, are these questions able to be posed.

A Gutless Biology?

Inagaki and Hatano argue that, well before the living/nonliving contrast is clearly mastered, biological and psychological processes are understood as distinct; quite possibly in the third year of life. To support their argument, Inagaki and Hatano present a huge array of research by themselves and others showing that preschoolers reason very differently about the psychological and biological. In many areas, such as disease contagion, bodily function, and inheritance of traits, young children are clearly aware that such processes are difficult to control through force of will and sharply contrast with the greater ease of controlling psychological processes such as social contagion or imitation. One recent example involves thought about whether negative traits are likely to improve at a future time. Even five-year-olds see negative psychological traits (e.g., being excessively messy) as more likely to change towards the positive than biological ones (e.g., being excessively short) [Lockhart, Chang, & Story, 2002]. Yet preschoolers, who show such facility at distinguishing the biological from the psychological, are remarkably ignorant of mechanism. They have no sense of how digestion actually works, of how diseases are really transmitted, or of how genetic material is responsible for the inheritance of properties. Inagaki and Hatano use this absence of mechanistic knowledge to motivate vitalism, but it also raises a fundamental question. How are preschoolers able to adeptly distinguish psychology from biology without any supporting mechanisms? As adults they might well refer to different mechanisms (e.g., belief/desire relations vs. physiological chains). Preschoolers have no such information on which to rely. Guts, innards, and other internal processes seem to play only a minimal role in their reasoning.

What, then, mediates these judgments of distinct domains? Vitalism, to be sure, plays an important role, as might teleology and essentialism. But are they enough? To know that John's beliefs are not transmitted to another person in the same way as his rash may not arise from simple vitalism. Perhaps, long before they sense specific mechanisms, children sense surprisingly abstract networks of causal patterns that are distinctive to psychology and biology. For example, they might note that many biological processes occur far beyond the phenomenal window of time we think of as the present. The effects of contagion are manifested days later, those of inheritance months or years later, and those of digestion hours or days later. Some psychological processes can also unfold very slowly over time, but most happen relatively quickly, not as instantaneously as physical mechanics but usually in a manner of seconds or minutes. I say something that causes another to respond in manner of seconds. I see something that causes me to act again within seconds, or even milliseconds.

The general time course patterns of biological and psychological causation are therefore different, and may be sensed very early on. Perhaps vitalism helps support this insight, but the insight could also occur on its own. This may be just one of many kinds of causal patterns used early on to sense the special nature of the biological world. We may sense that properties of an animal or plant are more mutually interacting than of many artifacts. Biological causal relations may be less probabilistically reliable than most mechanical events, such as simple collisions, but more so than many psychological ones. Hence, the probability distribution of causes creating effects may have a distinctive shape. In addition, once causal sequences are set in motion in biology they take a longer time to settle back to a steady state. Impregnation, wounds, or poisoning take on lives of their own that carry forth in ways that most simple, real world collisions do not. Psychological events also can carry forth but perhaps not in such apparent ways; they get diffusely connected to too many other things to make their original causes of a later behavior unambiguous in the way a germ or impregnation is related to its consequences. My point is simple. The set of causal patterns associated with living kinds is huge and much of it may be distinctive at a level far above that of mechanism [Simons & Keil, 1995]. Those patterns may be sensed early on and used to build up a network of expectations in which later mechanistic knowledge develops.

One final puzzle in this area concerns the lag between an understanding of the distinction between the biological and psychological by age 4, and an understanding of the living/nonliving distinction that occurs as much as a year later. If one can tell biological processes apart from psychological ones, doesn't one also know what living things are? Animals and plants are both seen as having vital forces and, thus, as soon as one uses vital forces to think about biological processes, why not use such forces to think about the larger superordinate category of both animals and plants as well? Perhaps this lag is an illusion that will disappear with more sensitive measures of the living/nonliving contrast. But if the lag holds up, it is important to understand its cause or else run the risk of admitting some incoherence in early biological thought. Perhaps abstract causal patterns are easier to grasp when thinking about specific biological processes, such as digestion or contagion, and harder when thinking about whole organisms, which is usually part of the living/nonliving tasks. Also, if biological thought is not monolithic (see below), thought about processes may tap into a vitalistic component while thought about species may tap into an adaptive component, with the two becoming integrated later on.

The Folk Biological Future

Inagaki and Hatano illustrate the unique insights that arise from the study of folk biology. They also show, as I hope this essay does, the sense of opportunity and promise for those interested in this area and the fascinating questions that remain.

How unified is biological thought in adults and in development? Inagaki and Hatano's treatment suggests that a single coherent mode of thought emerges; but is there only one folk biology or in fact several distinct domains loosely connected by a vague common notion of living things? In many universities, biology has split into two parts, ecology and systematics, and molecular biology. That contrast is often understood as evolutionary approaches vs. physiological ones and has been criticized in an age with ever more evolutionary explanations of molecular processes; but it resonates with two different research styles and ways of thinking. Young children have no real sense of evolutionary theory, but if we focus on adaptation, namely how organisms and their properties fit with their niches, it may point to an early division in biological thought. The tendency to construe kinds in taxonomic terms might be part of this adaptive bias and distinct from how they understand biological mechanisms, such as physiology.

How do children come to understand the origins of species, one of the most basic biological questions of all? We don't expect young children to understand evolution through natural selection, but what alternatives exist? There are of course religious beliefs and creation myths in many different traditions, but these may often be literary and romantic devices created by adults as opposed to reflections of people's best understandings of origins. This topic is not part of this book and just starting to get serious attention [Evans, 2000]. Why should it be so distinct an area of inquiry? Perhaps because people mostly just take species for granted and have no structured beliefs to explore, but even that speculation needs to be examined. Can one have a coherent folk biology and simply leave out notions of origins of species?

What patterns of conceptual change are illustrated in folk biology? Inagaki and Hatano outline four major kinds of conceptual change; but their analysis also illustrates the challenge of identifying a particular kind of conceptual change. One lesson from the years of work on the development of folk biology is that one theorist's description of a pattern of change as a conceptual revolution is another's description of the same pattern as incremental movement. For example, transitions from preschool to elementary school in reasoning about the functions of internal organs have either been described as part of a revolution from construing those functions in psychological terms to understanding them in biological ones, or as a gradual differentiation of understanding of mechanism. How can there be such disagreements over the same surface patterns of change? The answer requires a more extensive body of empirical and conceptual work showing how ambiguities arise and how they can be resolved.

To what extent is a biological thought part of implicit or explicit cognition? This question is recurring increasingly throughout cognitive development, and may be informed by a focus on folk biology. It now appears that some of the ways in which children and adults sense the distinctive nature of the living world occur at an implicit level, making efforts to measure folk biology in terms of explicit models incomplete. The contrast may also help us understand the confusions about patterns of conceptual change.

How shallow is biological thought both in children and in naïve adults? Explicit causal knowledge is usually of mechanism, implicit knowledge usually of more abstract general patterns. An interesting pattern seems to be emerging. Explicit understandings of biology may be shallower than they appear while implicit understandings may be richer.

I heard it once claimed that a detailed analysis of cognitive development in any domain, such as learning how to play chess or learning rules of etiquette, is just useful as any other domain because the same general insights would emerge. The domain picked is arbitrary and simply a matter of convenience. Inagaki and Hatano show in eloquent and powerful ways that the content of each domain and its specific causal structures matter greatly. Indeed, many of the most difficult and deepest questions in cognitive development are especially well informed by the study of the growth of biological thought.

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