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Running on Empty? How Folk Science Gets By With Less

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Abstract

Despite having highly impoverished understandings of the world at the mechanistic level, children and adults alike have strong interests in mechanistic explanations. These interests in mechanisms may support the development of folk-scientific understandings by enabling even the very young to build a sense of causal patterns that exist far above the level of mechanisms. That sense of causal patterns then works in combination with strategies for identifying and evaluating both experts and their explanations, enabling lay people of all ages to supplement their highly incomplete knowledge by accessing and relying on the divisions of cognitive labor that exist in all cultures.

Keywords

folk science, explanation, concepts, cognitive development

Folk science is often thought of as laypeople's mechanistic understandings of the natural and the artifactual worlds. Yet people of all ages have strikingly impoverished mechanistic understandings—often far worse than they assume. At the same time, even very young children have strong interests in mechanistic explanations and persistently seek them out. This fascination with and search for mechanism may support the tracking of causal structures and processes at levels far above that of mechanism. That information, in turn, enables people to bridge their extensive mechanistic gaps by identifying relevant experts. To be able to defer to experts effectively, even without mechanistic understanding, laypeople use a wide array of early-emerging heuristics for inferring causal relations and for evaluating experts and their explanations.

Although people in all cultures appear to have folk-scientific understandings of both nature and constructed devices, those understandings are often largely vacuous when considered at the level of mechanistic knowledge. The depth of this ignorance can be stunning. For example, functionally impossible schematic diagrams of mundane artifacts, such as simple bicycles, are falsely recognized as correct by large proportions of adults, and even by some devoted members of cycling clubs (Lawson, 2006). Thus, a schematic in which a bicycle's chain goes from the rear axle to the front one is endorsed by many adults even though that configuration would make steering impossible.

People's memory for the features of everyday objects, such as pennies, has long been known to be severely flawed. But even at the more abstract level of having a schematic sense of how everyday things work, we have only snatches and fragments—nothing like idealized schematic diagrams—in our heads. The problem is compounded by our sense that we have much more detailed explanatory understandings than we really do (Rozenblit & Keil, 2002), an illusion of explanatory depth that is especially strong in young children (Mills & Keil, 2004).

In short, knowledge of concrete mechanisms eludes not only children but also most adults. We appear to be blissfully gliding along, thinking we understand the world much better than we really do, in effect "running on empty." Yet this ignorance clashes with another well-documented phenomenon: the interest of young children in mechanisms.

Although children may occasionally ask "why" or "how" questions as ways of merely engaging adults, they often expect, and receive, mechanism-rich responses from them. Moreover, if the responses to such questions avoid mention of mechanisms or causal explanations, even preschoolers will persist in asking questions until they get such information (Callanan & Oakes, 1992; Frazier, Gelman, & Wellman, 2009; Mills, Legare, Grant, & Landrum, 2011; Wellman, 2011). They are also clearly able to adjust their course of questioning to pursue their informational needs (Chouinard, 2007), and the ways in which they adjust suggest an interest in and preference for mechanistic information. For example, if a child asks why the sky is blue and is told that all skies are blue, she will be

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more likely to then ask more "why" questions than she would if she had been given a mechanistic answer about air particles absorbing certain colors of light (such mechanistic answers can also invite further "why" questions, but they do so to a lesser extent).

Children do not always pursue mechanistic information, and important questions remain concerning the contexts and situations that prompt such queries (such as device malfunction; Isaacs, 1930; Legare, 2012), but on many occasions, they do seek out such information and acquire it either through direct experience or through testimony. Why should very young children have such an interest in mechanistic understanding if it seems to evaporate in the minds of all laypeople, leaving behind only the vaguest traces of specific mechanisms and isolated fragments of understanding (diSessa, Gillespie, & Esterly, 2004)?

Answering this question may depend on rethinking folk science as primarily tracking causal patterns at other levels, levels that can powerfully support folk science but cannot yield clockwork senses of how the world works (Keil, 2010). Indeed, there may be distinct advantages to usually having minimalist mechanistic understandings. In addition sophisticatedly tracking causal patterns that are "above" the level of mechanism, people of all ages use such patterns to infer fertile, or richly articulated, domains of expertise and guide themselves toward knowledge sources, and then use sophisticated strategies to evaluate those sources. In this article, I briefly describe research that has built on these ideas in four ways. Specifically, I consider (a) several different levels at which children, and sometimes even infants, can track causal information in nonmechanistic ways, (b) how children develop the ability to assess which domains are plausible areas of expertise, (c) ways in which young children can have huge mechanistic gaps but manage to infer causal patterns nonetheless, and (d) how children and adults outsource expertise and may actually benefit from illusions of understanding.

Levels of Tracking of Causal Information

Although mechanistic information may be difficult to remember in detail, attention to mechanism may enable memory for patterns at more abstract, nonmechanistic levels, memories that can be present in human infants and even in some other species. Several such levels are listed in Table 1. For example, at the most abstract level, one can notice *causal relevance* and *causal density*. We notice causal relevance when we track that certain types of properties, such as surface coloration, are typically causally connected to many other properties of most natural categories. In contrast, such causal connections to surface color are typically much less dense for properties of artifact categories (Keil, Smith, Simons, & Levin, 1998; Santos, Sulkowski, Spaepen, & Hauser, 2002). Similarly, one may know that some phenomena are much more causally complex than others even if the precise nature of that complexity remains unknown (Keil, 2010). At a more specific level, we also track causal powers. For example, preverbal infants believe that only animate intentional agents can create order out of disorder whereas a much wider range of agents can create disorder out of order (Newman, Keil, Kuhlmeier, &Wynn, 2010). They, as well as much older children, may have little sense of the mechanisms that underlie this causal power relation, but they know and use the pattern to interpret their world.

Beyond causal patterns, infants and young children can track broad functional properties of entities and categories. For example, although they are sometimes overly exuberant in ascribing functions to the natural world (Kelemen, 1999), they also know that it is more common to attribute functions to entire artifacts and their component parts than to entire animals (Greif, Kemler-Nelson, Keil, & Guttierez, 2006). High-level functional inferences are commonplace and often made in the context of observing intentional goal-directed actions by others, an ability present even in infancy (Csibra & Gergely, 2011).

All of these impressive abilities, however, do not translate into having blueprints of how things work, and they are often tacit. Thus, the child who thinks it more appropriate to talk about the functions of entire tools (e.g., what hammers are for) than of entire animals (e.g., what crows are for) may have never explicitly realized that contrast. Moreover, children often can be stunningly misguided about mechanistic details, a pattern that has spawned thousands of papers on children's misconceptions. These different levels of analysis (e.g., mechanistic vs. functional) can lead to claims that young children are either sophisticated scientists or hopelessly misguided. Beliefs about essence (Gelman, 2003) provide one example. Even preverbal infants seem to know that animals' insides are more essential to them than their outsides (Newman, Herrmann, Wynn, & Keil, 2008), yet school-age children can show striking errors in understanding how essences are actually physically instantiated in terms of biological components (Newman & Keil, 2008). Children and adults alike can sometimes grasp mechanistic fragments, such as a particular part of a physical or a biological system, but they have difficulty remembering how these fragments all fit together into a coherent system (diSessa et al., 2004).

There also may be a trend whereby, as people move to higher levels of abstraction, their tracking of casual patterns becomes more tacit. This pattern is proposed in the rightmost column in Table 1. It is suggested by cases in which patterns are tracked by preverbal infants and even nonhuman primates. Other suggestive evidence arises when participants express surprise at a pattern in their judgments that is disclosed in experimental debriefings. For example, many participants will report only realizing for the first time in an experiment their strong bias that it makes less sense to talk about the purposes of entire animals than of artifacts (Greif et al., 2006). Similarly, although infants may be strongly biased to prefer intentional agents as the causes of ordering events, even some adults can be startled at the extent to which they try to link intentional agency to departures from randomness (Newman

Table 1. Ways of Tracking Causal Relations

Kind of causal pattern	Characteristics	Developmental trajectory	Tacit vs. explicit
Causal relevancy	Tracking what kinds of causal properties are likely to be most explanatorily relevant to a domain	Appears in infancy among humans and some other species; continues to emerge throughout childhood	Tacit
Causal density	Tracking causal complexity and interconnectedness of properties for an entity or system	Emerges at least by preschool years; increases in sensitivity in early school years	Initially tacit
Causal powers	Knowing that an entity has the power to cause a particular kind of effect	Appears in infancy; expands considerably in preschool years	Both tacit and explicit
Functional relations	Knowing that a property or an entity serves a specific function	Appears in late infancy; functional attributions change in scope during preschool and early school years	Mostly explicit for specific functions; the tracking of abstract patterns of functional use (e.g., preference to think of functions of entire artifacts) may be tacit
Mechanistic fragments	Knowing the concrete details of isolated components of a system	Knowledge of some small fragments emerges in infancy; knowledge of larger and more numerous fragments develops throughout lifespan	Explicit
Full mechanistic details	Having a full mental blueprint of how something works	Develops very rarely and only for restricted domains among a few experts	Explicit

Note: Although much of the work on folk science has focused on full mechanistic understanding as the endpoint and goal of explanatory knowledge, most tracking of causal patterns occurs instead at levels that do not involve much mechanistic understanding at all. These other levels are intimately involved in identifying appropriate experts for deference and for evaluating the quality of explanations and of experts themselves. More abstract levels of tracking causal patterns may also be more tacit in nature.

et al., 2010). Future studies are needed to more systematically explore how tacit and explicit awareness of causal patterns vary according to the nature of those patterns and across development.

Accessing the Fertility of Domains

The tracking of causal patterns above the level of mechanism enables people of all ages to sense when a domain is likely an area of expertise as opposed to common knowledge that one needs no input from others to understand. Although young children show systematic biases in rating psychological phenomena as less complex than biological and physical phenomena (Keil, Lockhart, & Schlegel, 2010), even the youngest children are able to effectively distinguish between domains whose information is self-evident and domains whose understanding is heavily dependent on input from other minds (Keil, 2010). Indeed, there is now an increasing emphasis in the literature on the extent to which concepts are dependent on inputs from other minds (Gelman, 2009; Harris, 2012; Keil, 2010).

One particularly powerful result of children's search for mechanism may be the ways in which inquiry into mechanism instills other forms of knowledge. For example, as children strive to understand mechanisms, the details they learn may fade, but a sense of relative complexity persists; this perception of complexity is remarkably consistent across individuals, especially in the later elementary-school years and beyond (Kominsky, Zamm, & Keil, 2012). More broadly, the quest for mechanism may enable learning about causal relevance and density, powers and function. Thus, investigating mechanisms necessarily entails investigating all the other information as well, much of which may then be abstracted more implicitly and retained more fully than mechanistic information. Moreover, characterizing the degree and specific nature of a domain's complexity may be critical for identifying and evaluating experts.

Tricks for Tracking Causality

Because mechanistic understanding is weak, we have developed other strategies and heuristics for tracking important causal relations in the world, and we use these methods to discern causal powers and function without having to master mechanism. Consider two such strategies: overimitation and the stability heuristic.

Overimitation is the tendency to imitate all actions intentionally performed on a novel device and to automatically encode all those actions as causally central to the operation of the device even if they are mechanistically implausible (Lyons, Damrosch, Lin, Simeone, & Keil, 2011). In one paradigm, preschoolers are shown a "puzzle box" from which they are to retrieve a toy by manipulating knobs, levers, and other parts; however, only some of those parts are causally necessary for the retrieval. If an adult manipulates all the parts to retrieve the toy, observing preschoolers will do so as well, even though the casual connection between manipulating some of those parts and retrieving the toy is implausible. In contrast, chimpanzees drop the implausible steps (Horner & Whiten, 2005). Young humans often assume that others typically act "in good faith" when they operate devices and that all the parts they manipulate on the devices are being manipulated for important causal reasons that are central to the functioning of the device. These assumptions are a powerful, albeit fallible, shortcut toward inferring the causal underpinnings of artifacts. Automatic causal encoding may not always occur, as other social factors can also promote overimitation (Harris, 2012; Over & Carpenter, 2012); important questions about this issue and others remain about the conditions and contexts that promote the learning of causal powers from observations of others' actions.

The *stability heuristic* is used by people to explain changes in causal systems. People tend to assume that most properties of causal systems are fairly stable over time, and when they observe a change, they seek to attribute it to some cause. This heuristic is particularly useful when we don't know which of two parts of a causal system influences the other—when we are trying to identify the direction of the causal relationship. In particular, when considering a causal system with two parts that sometimes change simultaneously and at other times change independently while the corresponding part remains stable, people tend to infer that the more stable part influences the less stable part, but not vice versa (Rottman & Keil, 2012). This heuristic greatly enhances the learning of causal relationships that unfold over time. It is challenging to integrate the learning of such temporal causal patterns into standard models of causal learning that have focused on nontemporal scenarios with independent trials (e.g., Gopnik et al., 2004).

The Outsourcing of Understanding and the Virtues of Illusions of Knowing

Once an individual has learned that a class of phenomena is sufficiently complex for an understanding of it to warrant the need for outside expertise, the challenge remains of identifying appropriate experts. Three classes of processes converge to make this happen. The first uses abstract causal patterns to match classes of phenomena to appropriate experts. The second uses an array of heuristics to evaluate the likely quality of individual experts. The third examines the internal structure of explanations to assess their quality. Although such skills might seem to emerge late in development and to be hallmarks of sophisticated scientific thought, they start to emerge early and form a foundational framework that guides deference in understanding.

In terms of using causal patterns to seek out appropriate experts, even preschoolers can extrapolate from one thing an expert knows to what else she or he is likely to know, and they do so in ways that go far beyond matching surface similarities. Thus, they will realize that an expert on one problem in biology is more likely to be an expert on another problem in biology than is an expert on a problem in physical mechanics (Lutz & Keil, 2002). Moreover, children use abstract causal schematic patterns to construct such mappings (Keil, Stein, Webb, Billings, & Rozenblit, 2008): When children hear that a person is an expert on a particular phenomenon, they sense some of the core underlying causal patterns associated with that phenomenon and then infer what other phenomena are governed by the same underlying causal patterns. They then assume that the expert is more likely than other people to know about those phenomena as well.

Several heuristics are also used early in life to evaluate experts. For example, young children prefer experts who have made fewer errors in the past and whose opinions agree more often with consensus (Harris & Corriveau, 2011). In addition, by the early school years, children start to be sensitive to conflicts of interest as reasons to doubt experts, assuming that a person's assertions might be suspect if they are strongly aligned with helping achieve a goal (Mills & Keil, 2004).

Finally, expressions of expertise themselves can be evaluated for their internal quality—for instance, in terms of their coherence, simplicity, and informativeness (Frazier et al., 2009; Lombrozo, 2007). More developmental growth seems to be required for this skill, which tends to emerge more dramatically during the elementary-school years, but still well ahead of exposure to formal instruction on the nature of scientific thought. For example, by second grade, children start to understand the vacuous nature of circular arguments and explanations (Baum, Danovitch, & Keil, 2008).

Successful navigation of the division of cognitive labor requires mastery and integration of each of these processes, elements of which all emerge early in life and without explicit instruction. These processes buttress our own partial understandings right from the start. They are not late-acquired nuances of the ways in which we understand the world and form our concepts; they are instead intrinsic to understanding at any age.

Summary

Even though the youngest child has an intrinsic fascination with mechanism, the most sophisticated adult, outside of narrow areas of expertise, displays yawning gaps in mechanistic knowledge. Yet an interest in mechanism helps even young children build a sense of causal patterns that exist far above the level of mechanisms. That sense, in combination with strategies for identifying and evaluating experts and their explanations, allows us all to ground our incomplete knowledge in more secure footings in other minds. This is hardly a foolproof method, as many cases of public misunderstandings of science reveal, but the early emergence of these strategies suggests that, rather than become overwhelmed with mechanistic details that would swamp any one person's cognitive capacities, even the youngest among us have learned sophisticated ways of relying on the contents of other minds.

Recommended Reading

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