signals may be found in widely divergent protein localization pathways, not just during protein secretion.

Additional work will reveal whether mRNA signals represent a general protein localization strategy or if they remain exceptional examples. For example, a recent report revealed that several transcripts in *E. coli* and *Caulobacter crescentus* also localize specifically, but that they remained very close to the chromosomal site where they were synthesized (*9*). In any case, the observations that mRNA molecules localize specifically within a bacterium predict the existence of pathways that mediate this localization, and these components will need to be identified. It appears that mRNA can contribute not simply to encoding proteins, but to delivering them as well.

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PSYCHOLOGY

Science Starts Early

Frank C. Keil

Infants and children grasp surprisingly sophisticated correlational and causal patterns.

Infants and young children can exhibit striking confusion about how the world works, from failing to grasp that wind causes waves, to being mystified about how babies are created. Indeed, some researchers have characterized a child's knowledge of the world as a bundle of misconceptions awaiting replacement with correct concepts through education (*1*).

Evidence is mounting, however, that young children are often quite adept at uncovering statistical and causal patterns and that many foundations of scientific thought are built impressively early in our lives. This growing understanding of how children acquire many of the thinking skills used in science has implications not only for education but also for understanding how all of us make scientific progress in the face of ignorance and incomplete knowledge.

For cognitive psychologists, scientists have long presented an intriguing puzzle. Whether a biologist or a geologist, scientists routinely, and with seeming ease, call upon a diverse set of cognitive skills to do their jobs. They detect correlations, often between seemingly unrelated phenomena. They infer causation from these correlations. If all goes well, they uncover the mechanisms that explain it all—and then share their knowledge and build upon it by acquiring knowledge from others.

Each of these abilities has early origins. Consider, for example, how children respond to the challenge of noticing correlations as they encounter them in the flow of experience. For instance, an infant learning language, upon hearing streams of syllables, not only has to notice how often certain syllables occur but also needs to infer higher-order patterns arising from those syllables. One study (*2*) showed that 5-month-old infants can handle this challenge by rapidly tracking not only the sounds of the syllables but also visual patterns associated with each syllable. In the experiment, infants looking at a computer screen were repeatedly presented with abstract patterns of syllables and shapes. An "ABB" pattern, for instance, could be represented by certain shapes corresponding to the syllables "di ga ga." When presented with a new pattern (ABA) with new syllables—such as "le ko le"—the infants looked longer at the shapes on the screen than if the new syllables were in the old ABB pattern. This suggests that they recognized it as a new, unfamiliar correlation.

Other research (*3*) has found that 6-month-olds can take the next step and infer causation from certain kinds of correlations. In these experiments, researchers measured how long infants looked at animations showing "collisions" of shapes. In some animations, one object "launched" a second one, causing it to move, as when two billiard balls collide. When shown animations in which the balls reversed roles, infants looked longer at the new pattern than at the original one. They did not react as strongly, however, when the original and reversed animations contained half-second gaps between the moment when the first object stopped moving and the second one started to move. This suggests that the infants recognized these events as noncausal, or unrelated.

Later studies showed that infants make causal interpretations by integrating information in ways that closely mirror adults. For instance, they will form causal interpretations based on information that is collected in brief time windows after the occurrence of the critical event (such as a possible collision) (*4*); these post-event decision-making windows are similar to those measured in adults. Thus, it appears that certain sequences of events automatically elicit thoughts of causation at all ages.

Older infants expand on these inferences of causality to sense more abstract and subtle causal relationships. In one recent study (*5*), 11-month-olds were shown animations of two sets of blocks: one initially ordered into a neat array, the other scattered into disorder. Then, a screen obscured the blocks and either a lifelike "animate" agent appeared, such as an object with a face, or an "inanimate" agent, such as a ball. Finally, the screen was removed, revealing that either an orderly stack of blocks had become disordered or the opposite. By measuring how long the infants looked at various combinations, the researchers concluded that the infants learned that only the animate object could cause disordered blocks to become orderly but that both the animate and inanimate agents could scatter an orderly pile.

Once out of infancy, children become able to examine more complex networks of correlations to infer causal patterns, including hidden ones, and they readily do this using sample sizes too small for traditional statistical tests of significance. They are particularly sensitive to the usefulness of "intervening on a system"—or manipulating conditions—to separate causal links from those that are just correlational. For example, when confronted with a novel box consisting of gears and a switch, preschool children are easily able to figure out cause-and-effect relations, and rule out mere cor-

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Department of Psychology, Yale University, New Haven, CT 06520–8205, USA. E-mail: frank.keil@yale.edu

relations, by manipulating key components and observing the consequences (*6*). Thus, they anticipate a key motivation of experimental design, in which some variables are manipulated while others are held constant.

In addition to figuring out the causal relations underlying novel devices, children are also sensitive to highly abstract causal patterns associated with specific "domains" that correspond roughly to formal areas of science, such as biology, physical mechanics, and psychology. For example, while being completely ignorant about the biological details, most preschoolers do know that food gets transformed after it enters the body and that the transformed version is critical for helping the body to grow and to move (*7*). Some of these "core knowledge" domains may have origins in infancy and then become combined into larger conceptual systems in childhood (*8*).

Budding scientist. Many aspects of scientific understanding appear early.

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A child's understanding of the world is not driven simply by assembling correlations in a bottom-up manner. Instead, even very young children bring to most learning situations broad intuitions and expectations about plausible and implausible patterns. This kind of top-down analysis enables them to rule out or narrow an overwhelming range of possible correlations (*9*). For example, in thinking about biological phenomena such as disease or inheritance, children may make different inferences from patterns of covariation than they do for physical phenomena such as collisions or rotating gears (*10*). Another top-down expectation that children bring to living things, but not to artifacts, is an "essentialist bias": the idea that something you can't see (e.g., "microstructural stuff") causes what you can see ("surface phenomena" such as feathers or fur) and is the essence of the thing being observed. This is a guiding principle in much of formal science, even as it can also lead to false inferences, such as that species are defined by fixed essences (*11*).

Science education should build upon these early-emerging cognitive foundations. Like the vast majority of adults, children need instruction about detailed mechanisms, but they also bring to the classroom a rich repertoire of skills that enable them to track patterns and infer causality in ways that constrain and support learning about specific mechanisms. Educational strategies that leverage those skills, such as connecting mechanism information (e.g., natural selection) to a higher-level causal pattern children already know (e.g., adaptation), will have a huge head start over those that do not (*12*).

The study of formal science is also informed by studies of children. Recent research reveals how all of us are able to accumulate knowledge with only partial understanding of mechanisms outside our own narrow areas of expertise (*13*). Scientists use their senses of more abstract causal and correlational patterns to navigate and rely on the divisions of cognitive labor that are essential to scientific progress. Thus, all scientists must outsource some understanding to other experts by grasping the coarse causal and correlational patterns associated with distinct areas of expertise. We are only beginning to understand how they find the right depth of analysis in their own areas for optimal progress and then link that work to research done by others (*14*).

Future studies must explore how children, and adults, can build upon these foundations. How, for instance, can we prevent the essentialist biases and other narrowing strategies that children use to understand the world from lingering into adulthood and impairing scientific reasoning (*15*)? Imbuing organisms with fixed essences, for example, can impair understanding of natural selection (*16*), and a child's assumption that order is created by intentional agents (*5*) can ultimately impair recognition of other order-creating forces such as those at work in evolution. Finally, we need to examine the relationship between implicitly tracking patterns and explicitly characterizing their natures. Taken together, these future studies will continue to transform how we all think about the scientific skills of children. Rather than bumbling babies, they are individuals who—right from the start—are deeply interested in and can learn surprisingly fast about the patterns of nature.

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