# How Babies Think

## Even the youngest children know, experience and learn far more than scientists ever thought possible

BY ALISON GOPNIK

Photographs by Timothy Archibald

### KEY CONCEPTS

- Babies' and young children's cognitive abilities far surpass those that psychologists long attributed to them. They can, for instance, imagine another person's experiences and grasp cause and effect.
- Children learn about the world much as scientists do—in effect, conducting experiments, analyzing statistics and forming theories to account for their observations.
- The long helplessness of babies may be an evolutionary trade-off, a necessary consequence of having brains wired for prodigious feats of learning and creativity.

*—The Editors*

THIRTY YEARS AGO most psychologists, philosophers and psychiatrists thought that babies and young children were irrational, egocentric and amoral. They believed children were locked in the concrete here and now—unable to understand cause and effect, imagine the experiences of other people, or appreciate the difference between reality and fantasy. People still often think of children as defective adults.

But in the past three decades scientists have discovered that even the youngest children know more than we would ever have thought possible. Moreover, studies suggest that children learn about the world in much the same way that scientists do—by conducting experiments, analyzing statistics, and forming intuitive theories of the physical, biological and psychological realms. Since about 2000, researchers have started to understand the underlying computational, evolutionary and neurological mechanisms that underpin these remarkable early abilities. These revolutionary findings not only change our ideas about babies, they give us a fresh perspective on human nature itself.

### PHYSICS FOR BABIES

WHY WERE WE so wrong about babies for so long? If you look cursorily at children who are four years old and younger (the age range I will discuss in this article), you might indeed conclude that not much is going on. Babies, after all, cannot talk. And even preschoolers are not good at reporting what they think. Ask your average three-year-old an open-ended question, and you are likely to get a beautiful but incomprehensible stream-of-consciousness monologue. Earlier researchers, such as the pioneering Swiss psychologist Jean Piaget, concluded that children's thought itself was irrational and illogical, egocentric and "precausal"—with no concept of cause and effect.

The new science that began in the late 1970s depends on techniques that look at what babies and young children do instead of just what they say. Babies look longer at novel or unexpected events than at more predictable ones, and experimenters can use this behavior to figure out what babies expect to happen. The strongest results, however, come from studies that observe actions as well: Which objects do babies reach for or crawl to? How do babies and young children imitate the actions of people around them?

Although very young children have a hard time telling us what they think, we can use language in more subtle ways to tease out what they know. For example, Henry Wellman of the University of Michigan at Ann Arbor has analyzed recordings of children's spontaneous conversations for clues to their thinking. We can give chil-

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dren very focused questions—for instance, asking them to choose between just two alternatives, rather than asking an open-ended question.

In the mid-1980s and through the 1990s, scientists using these techniques discovered that babies already know a great deal about the world around them. That knowledge goes well beyond concrete, here-and-now sensations. Researchers such as Renée Baillargeon of the University of Illinois and Elizabeth S. Spelke of Harvard University found that infants understand fundamental physical relations such as movement trajectories, gravity and containment. They look longer at a toy car appearing to pass through a solid wall than at events that fit basic principles of everyday physics.

By the time they are three or four, children have elementary ideas about biology and a first understanding of growth, inheritance and illness. This early biological understanding reveals that children go beyond superficial perceptual appearances when they reason about objects. Susan A. Gelman, also at Michigan, found that young children believe that animals and plants have an "essence"—an invisible core that stays the same even if outside appearances change.

For babies and young children, the most important knowledge of all is knowledge of other people. Andrew N. Meltzoff of the University of Washington showed that newborns already understand that people are special and will imitate their facial expressions.

In 1996 Betty Repacholi (now at Washington) and I found that 18-month-olds can understand that I might want one thing, whereas you want another. An experimenter showed 14- and 18-month-olds a bowl of raw broccoli and a bowl of goldfish crackers and then tasted some of each, making either a disgusted face or a happy face. Then she put her hand out and asked, "Could you give me some?" The 18-month-olds gave her broccoli when she acted as if she liked it, even though they would not choose it for themselves. (The 14-month-olds always gave her crackers.) So even at this very young age, children are not completely egocentric—they can take the perspective of another person, at least in a simple way. By age four, their understanding of everyday psychology is even more refined. They can explain, for instance, if a person is acting oddly because he believes something that is not true.

By the end of the 20th century experiments had thus charted impressively abstract and sophisticated knowledge in babies and the equally impressive growth of that knowledge as children get older. Some scientists have argued that babies must be born knowing much of what adults know about how objects and people behave. Undoubtedly, newborns are far from being blank slates, but the changes in children's knowledge also suggest that they are learning about the world from their experiences.

One of the greatest mysteries of psychology and philosophy is how human beings learn about the world from a confusing mess of sensory data. Over the past decade researchers have begun to understand much more about how babies and young children can learn so much so quickly and accurately. In particular, we have discovered that babies and young children have an extraordinary ability to learn from statistical patterns.

## THE STATISTICS OF BLICKETS

IN 1996 Jenny R. Saffran, Richard N. Aslin and Elissa L. Newport, all then at the University of Rochester, first demonstrated this ability in studies of the sound patterns of language. They played sequences of syllables with statistical regularities to some eight-month-old babies. For example, "bi" might follow "ro" only one third of the time, whereas "da" might always follow "bi." Then they played the babies new strings of sounds that either followed these patterns or broke them. Babies listened longer to the statistically unusual strings. More recent studies show that babies can detect statistical patterns of musical tones and visual scenes and also more abstract grammatical patterns.

Babies can even understand the relation between a statistical sample and a population. In a 2008 study my University of California, Berkeley, colleague Fei Xu showed eight-month-old babies a box full of mixed-up Ping-Pong balls: for instance, 80 percent white and 20 percent red. The experimenter would then take out five balls, seemingly at random. The babies were more surprised (that is, they looked longer and more intently at the scene) when the experimenter pulled four red balls and one white one out of the box—an improbable outcome—than when she pulled out four white balls and one red one.

Detecting statistical patterns is just the first step in scientific discovery. Even more impressively, children (like scientists) use those statistics to draw conclusions about the world. In a version of the Ping-Pong ball study with 20-month-old babies using toy green frogs and yellow ducks, the experimenter would take five toys from the box and then ask the child to give her a toy from some that were on the table. The children showed

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no preference between the colors if the experimenter had taken mostly green frogs from the box of mostly green toys. Yet they specifically gave her a duck if she had taken mostly ducks from the box—apparently the children thought her statistically unlikely selection meant that she was not acting randomly and that she must prefer ducks.

In my laboratory we have been investigating how young children use statistical evidence and experimentation to figure out cause and effect, and we find their thinking is far from being "precausal." We introduce them to a device we call "the blicket detector," a machine that lights up and plays music when you put some things on it but not others. Then we can give children patterns of evidence about the detector and see what causal conclusions they draw. Which objects are the blickets?

In 2007 Tamar Kushnir, now at Cornell University, and I discovered that preschoolers can use probabilities to learn how the machine works. We repeatedly put one of two blocks on the machine. The machine lit up two out of three times with the yellow block but only two out of six times for the blue one. Then we gave the children the blocks and asked them to light up the machine. These children, who could not yet add or subtract, were more likely to put the high-probability yellow block on the machine.

They still chose correctly when we waved the high-probability block over the machine, activating it without touching it. Although they thought this kind of "action at a distance" was unlikely at the start of the experiment (we asked them), these children could use probability to discover brand-new and surprising facts about the world.

In another experiment Laura Schulz, now at the Massachusetts Institute of Technology, and I showed four-year-olds a toy with a switch and two gears, one blue and one yellow, on top. The gears turn when you flip the switch. This simple toy can work in many ways. Perhaps the switch makes both gears turn at once, or perhaps the switch turns the blue gear, which turns the yellow one, and so on. We showed the children pictures illustrating each of these possibilities—the yellow gear would be depicted pushing the blue one, for instance. Then we showed them toys that worked in one or the other of these ways and gave them rather complex evidence about how each toy worked. For example, the children who got the "causal chain toy" saw that if you removed the blue gear and turned the switch, the yellow gear would still turn but that if you removed the yellow gear and turned the switch, nothing happened. We asked the children to pick the picture that matched how the toy worked. Four-year-olds were amazingly good at ascertaining how the toy worked based on the pattern of evidence that we presented to them. Moreover, when other children were just left alone with the machine, they played with the gears in ways that helped them learn how it worked—as if they were experimenting.

Another study by Schulz used a toy that had two levers and a duck and a puppet that popped up. One group of preschoolers was shown that the duck appeared when you pressed one lever and that the puppet popped up when you pressed the other one. The second group saw that when you pressed both levers at once, both toys popped up, but they never got a chance to see what the levers did separately. Then the experimenter had the children play with the toy. Children from the first group played with the toy much less than those from the second group. They already knew how it worked and were less interested in exploring it. The second group faced a mystery, and they spontaneously played with the toy, soon uncovering which lever did what.

These studies suggested that when children play spontaneously ("getting into everything")

## STATISTICIAN AT WORK

Babies are skillful statistical analysts. Experiments showed that eight-month-olds notice if an improbable number of red Ping-Pong balls are taken out of a collection that is mostly white. Variations of the experiments (such as swapping the role of red and white) control against alternative explanations (such as having a greater interest in red objects). Twenty-month-olds tested with green and yellow toys inferred that a person taking an unusually large number of the rare color would prefer to be given a toy of that color. Thus, babies and young children learn about the world like scientists—by detecting statistical patterns and drawing conclusions from them.

they are also exploring cause and effect and doing experiments—the most effective way to discover how the world works.

## THE BABY COMPUTER

**OBVIOUSLY CHILDREN ARE NOT** doing experiments or analyzing statistics in the self-conscious way that adult scientists do. The children's brains, however, must be unconsciously processing information in a way that parallels the methods of scientific discovery. The central idea of cognitive science is that the brain is a kind of computer designed by evolution and programmed by experience.

Computer scientists and philosophers have begun to use mathematical ideas about probability to understand the powerful learning abilities of scientists—and children. A whole new approach to developing computer programs for machine learning uses what are called probabilistic models, also known as Bayesian models or Bayes nets. The programs can unravel complex gene expression problems or help understand climate change. The approach has also led to new ideas about how the computers in children's heads might work.

Probabilistic models combine two basic ideas. First, they use mathematics to describe the hypotheses that children might have about things, people or words. For example, we can represent a child's causal knowledge as a map of the causal relations between events. An arrow could point from "press blue lever" to "duck pops up" to represent that hypothesis.

Second, the programs systematically relate the hypotheses to the probability of different patterns of events—the kind of patterns that emerge from experimentation and statistical analysis in science. Hypotheses that fit the data better become more likely. I have argued that children's brains may relate hypotheses about the world to patterns of probability in a similar way. Children reason in complex and subtle ways that cannot be explained by simple associations or rules.

Furthermore, when children unconsciously use this Bayesian statistical analysis, they may actually be better than adults at considering unusual possibilities. In a study to be presented at a conference later this year, my colleagues and I showed four-year-olds and adults a blicket detector that worked in an odd way, requiring two blocks on it together to make it go. The four-year-olds were better than the adults at grasping this unusual causal structure. The adults seemed to rely more on their prior knowledge that things usually do not work that way, even though the evidence implied otherwise for the machine in front of them.

In other recent research my group found that young children who think they are being instructed modify their statistical analysis and may become less creative as a result. The experimenter showed four-year-olds a toy that would play music if you performed the right sequence of actions on it, such as pulling a handle and then squeezing a bulb. For some children, the experimenter said, "I don't know how this toy works—let's figure it out." She proceeded to try out various longer action sequences for the children, some that ended with the short sequence and made music and some that did not. When she asked the children to make the toy work, many of them tried the correct short sequence, astutely omitting actions that were probably superfluous based on the statistics of what they had seen.

With other children, the experimenter said that she would teach them how the toy worked by showing them sequences that did and did not produce music, and then she acted on the toy in exactly the same way. When asked to make the

## NATURAL EXPERIMENTERS

Four-year-olds are adept at interpreting evidence to learn about cause and effect, such as determining if one cog on a machine is turning another (*below*). Some even carried out the correct experiments (and drew the right conclusion) while freely "playing" with the toy. Research involving a "blicket detector" (*opposite page*), which is more likely to light up for some combinations of blocks than for others, found that four-year-olds could use statistics to learn how the machine worked, even when it showed new, unexpected behavior. Indeed, they were more open-minded than adults when faced with evidence that the machine responded to blocks in an unusual way.

toy work, these children never tried a shortcut. Instead they mimicked the entire sequence of actions. Were these children ignoring the statistics of what they saw? Perhaps not—their behavior is accurately described by a Bayesian model in which the "teacher" is expected to choose the most instructive sequences. In simple terms: if she knew shorter sequences worked, she would not have shown them the unnecessary actions.

## EVOLUTION AND NEUROLOGY

IF THE BRAIN is a computer designed by evolution, we can also ask about the evolutionary justification and neurological basis for the extraordinary learning abilities we see in very young children. Recent biological thinking is in close accord with what we see in the psychology lab.

From an evolutionary perspective, one of the most striking things about human beings is our long period of immaturity. We have a much longer childhood than any other species. Why make babies so helpless for so long and thus require adults to put so much work and care into keeping their babies alive?

Across the animal kingdom, the intelligence and flexibility of adults are correlated with the immaturity of babies. "Precocial" species such as chickens rely on highly specific innate capacities adapted to one particular environmental niche, and so they mature quickly. "Altricial" species (those whose offspring need care and feeding by parents) rely on learning instead. Crows, for instance, can take a new object, such as a piece of wire, and work out how to turn it into a tool, but young crows depend on their parents for much longer than chickens.

A learning strategy has many advantages, but until learning takes place, you are helpless. Evolution solves this problem with a division of labor between babies and adults. Babies get a protected time to learn about their environment, without having to actually do anything. When they grow up, they can use what they have learned to be better at surviving and reproducing—and taking care of the next generation. Fundamentally, babies are designed to learn.

Neuroscientists have started to understand some of the brain mechanisms that allow all this learning to occur. Baby brains are more flexible than adult brains. They have far more connections between neurons, none of them particularly efficient, but over time they prune out unused connections and strengthen useful ones. Baby brains also have a high level of the chemicals that make brains change connections easily.

The brain region called the prefrontal cortex is distinctive to humans and takes an especially long time to mature. The adult capacities for focus, planning and efficient action that are governed by this brain area depend on the long learning that occurs in childhood. This area's wiring may not be complete until the mid-20s.

The lack of prefrontal control in young children naturally seems like a huge handicap, but it may actually be tremendously helpful for learning. The prefrontal area inhibits irrelevant thoughts or actions. But being uninhibited may help babies and young children to explore freely. There is a trade-off between the ability to explore creatively and learn flexibly, like a child, and the ability to plan and act effectively, like an adult. The very qualities needed to act efficiently—such as swift automatic processing and a highly pruned brain network—may be intrinsically antithetical to the qualities that are useful for learning, such as flexibility.

A new picture of childhood and human nature emerges from the research of the past decade. Far from being mere unfinished adults, babies and young children are exquisitely designed by evolution to change and create, to learn and explore. Those capacities, so intrinsic to what it means to be human, appear in their purest forms in the earliest years of our lives. Our most valuable human accomplishments are possible because we were once helpless dependent children and not in spite of it. Childhood, and caregiving, is fundamental to our humanity. ■


## MORE TO EXPLORE

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