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Hitting the Curiosity Sweet Spot Speeds Up Learning

Understanding curiosity can help people—and robots—learn faster

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The world is full of things to learn. Where to start? How to choose what to pay attention to? What motivates someone to seek new knowledge?

The desire to learn is partly a preference for novelty: we tend to seek out new information and experiences, and that adds to what we know. We also like to reduce uncertainty. Information can bring food, safety, relationships, and other physical rewards. But scientists now believe these drives combine into a more complicated urge that can be critical to learning, even when—perhaps especially when—there's no immediate payoff. We are just curious.

We're often curious in a particular way: we want to learn more about things we already know a little bit about. "You can think of curiosity as the process that guides the acquisition of knowledge," says neuroscientist Celeste Kidd of the University of California, Berkeley. We internally track how well we are learning, or our learning progress, and learning comes more easily and is more enjoyable when curiosity is high. Following our instincts appears to be a particularly rewarding way to explore the world. "If you feel positive after learning something, then you now understand the joy of learning, which motivates you to learn next time," says educational psychologist Kou Murayama of the University of Tübingen in Germany.

Kidd and Murayama are among many investigators, in fields as diverse as neuroscience, education, psychology and computational science, who are curious about curiosity. This new research focuses less on curiosity as an individual trait—one that many scholars and artists possess, as do you, the reader of an article on curiosity—and more on the variable state of being curious. Each of us is capable of curiosity, but what sparks and sustains it?

Scientists are piecing together the brain processes that underlie the wide-eyed wanting-to-know we generally think of as being curious. They are identifying how the brain homes in on novelty, copes with uncertainty, triggers reward networks and solidifies memory. Researchers are also beginning to see why curiosity can be so consequential.

“It becomes obvious that what we should value is learning.” —Jacqueline Gottlieb, cognitive neuroscientist

The instinct can be dangerous on occasion—curiosity famously killed the cat—but overall, it seems to encourage exploration in ways that promote survival. Gathering information even when its purpose is unclear allows us to build more accurate mental models of our world, says comparative psychologist Victor Ajuwon of the University of Cambridge, who studies elements of curiosity in rats, goldfish and cuttlefish. “That is going to be useful for you in the future,” he says.

This link between curiosity, which occurs moment to moment, and the longer timescales of development and evolution is a new way of thinking, says Pierre-Yves Oudeyer of French research institute Inria in Bordeaux. Setting your own goals seems to increase motivation and let learning blossom in a sweet spot between challenge and frustration. Russian educational psychologist Lev Vygotsky called it “the zone of proximal development.” But until recently, little attention has been paid to what might be happening cognitively to make curiosity’s sweet spot so, well, sweet.

All humans know what it is to be curious, and we generally think of it as a positive trait, associating it with intrinsic motivation, creativity and open-mindedness. Influential early thinkers captured important aspects that are still thought to hold true. In 1966 psychologist Daniel Berlyne recognized that curiosity could relate to perception, such as when we notice a visual incongruity like a zebra among horses, and it could be specific or wide-ranging. In 1994 behavioral economist George Loewenstein theorized that curiosity was caused by the need to fill an information gap. Comprehending how curiosity works, Kidd says, means understanding "how people form their beliefs about the world and how they change their minds." A deeper analysis of the neural underpinnings and role of curiosity could potentially show teachers how to reach students more effectively, enable computer scientists to program artificial-intelligence systems to learn efficiently, and alleviate suffering from some mental disorders. Knowing how to facilitate curiosity about other kinds of people and cultures may even help make the world a kinder place.

Curiosity didn't get a lot of scientific attention until now, because it is difficult to define. Are all urges to know driven by curiosity? In a review published earlier this year, Jamie J. Jirout of the University of Virginia and her co-workers posit that curiosity "must arise from an internal desire for information" for its own sake. So, for example, a child asking why a rainbow happens is probably driven by curiosity if they just saw one—but not if the question is prompted by a science exam the next day. (Nor is curiosity the craving to know the outcome of a biopsy, which can be more like dread.) Some researchers study information seeking as a whole without trying to separate out curiosity.

Curiosity can on occasion be disconcerting, even distressing. People desperate to know, for example, the secret behind a magic trick have been willing to accept mild electric shocks as the price of satisfying their curiosity sooner. And arguments in pubs led an executive at the Guinness brewery to create the company's eponymous book of records and then distribute its first copies in drinking establishments, the better to settle future disagreements immediately. (Have you ever wondered what a beer company and the world's largest ball of string had to do with each other?)


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"Curiosity in Children across Ages and Contexts," by Jamie J. Jirout, Natalie S. Evans and Lisa K. Son, in *Nature Reviews Psychology*, Vol 3; August 2024; restyled by Jen Christiansen

More often, though, curiosity is delicious. Studies show we happily avoid spoilers so as not to lose out on the fun of an unfolding drama. If you missed the Super Bowl or the series finale of *Succession*, you probably went well out of your way to keep from finding out what happened too soon. Nowadays we all carry digital reference libraries in our pockets, and we have a hard time resisting the need to use them as soon as a nagging question arises. Researchers measure the tip-of-the-tongue feeling, which heightens curiosity, by assessing the strength of the urge to google an answer. (Appropriately, they also liken the feeling to "mild torment.")

It's probably the anticipation of an answer that feels delectable. Higher levels of curiosity lead to higher levels of activity in areas such as the striatum, which is involved in the release of dopamine, the neurotransmitter most associated with feelings of reward. The dopamine link "seems to resonate with this idea that curiosity is an internal reward, and then definitely it's a motivator," says cognitive neuroscientist Jacqueline Gottlieb of Columbia University's Zuckerman Institute.

To work out that information itself is rewarding, neuroscientists have had to show how the brain distinguishes between physical rewards and information. Such work started in monkeys, the first other species in which scientists, who fear anthropomorphic overreach, have felt confident claiming curiosity exists. (No surprise to fans of Curious George.) Neuroscientist Benjamin Hayden of the University of Minnesota and his colleagues set up an experiment in which monkeys got water as a treat, and the researchers gave them the opportunity to find out ahead of time whether that reward was coming. The monkeys chose to get a heads-up 80 to 90 percent of the time and were even willing to lose out on larger rewards to know. They are saying, in effect, "I'm so curious that I want this information now," Hayden says.

Mice appear to show the same tendencies, according to a study by psychologist Jennifer Bussell, a postdoctoral researcher at the Zuckerman Institute. Moreover, in both monkeys and mice, neurons in the orbitofrontal cortex (OFC), which is involved in an early stage of decision-making, responded differently to water rewards and to cues—information—that predicted those rewards. The OFC neurons encode details such as the amount of water as independent variables to be compared later, rather like raw material that will feed into their choice.

"There's probably a drive that evolved to learn new stuff and gather information because 99 percent of the time in the natural world, for an animal, information is useful," Bussell says. "Evolutionarily, you have to nudge the creature to come out of its burrow, even if it's afraid that there's a predator coming." If the brain builds a system that regards gathering information and reducing uncertainty as rewarding, "that kind of solves the problem," she says.

Reflecting the evolutionary significance of curiosity, the work of taking the raw material encoded by the OFC neurons and integrating the two different kinds of values—information and physical rewards—occurs in a small, ancient structure in the midbrain called the lateral habenula, according to a 2024 study by neuroscientist Ilya Monosov and others at Washington University in St. Louis. The lateral habenula, which exists across many species, assesses the relative importance of possible motivations, Monosov says. “In your daily life, you rarely make decisions based on either physical reward or secondary rewards, like money alone or information seeking alone,” he says. Instead our brains do the complicated work of comparing our concrete needs and our curiosity—Should I go to bed now and get enough sleep or finish reading the whodunit?—and weighing one against the other.

Other parts of the brain also grapple with uncertainty. In a 2024 study, Gottlieb and her colleagues explored perceptual curiosity by having participants view sets of images of animals and inanimate objects, such as a walrus and a hat. The brain clearly distinguishes animate from inanimate objects with neuronal signals that Gottlieb calls the equivalent of “barcodes,” a feature the researchers wanted to use. The images also varied in their clarity from easily identifiable to completely mysterious. When people were confident about what they were looking at, the barcodes in the visual parts of their brains flashed clear signals: animate or inanimate. But when people weren’t sure, the signals fell somewhere in between. And when the signals from the vision area reached the frontal cortex, where decisions get made, they triggered either confidence or curiosity. “The more uncertain this visual part of their brain was, the more curious people said they were,” Gottlieb explains.

Curiosity also primes memory circuits, the better to retain the new information. Presented with trivia questions—What Beatles single lasted longest on the charts? What is the only known place on Earth where trees have square trunks?—participants in a 2014 study rated their curiosity about the answers. (Don't worry, I'll share them at the end.) Then, in a functional magnetic resonance imaging machine, they had to wait 14 seconds to get those answers. While waiting, they were shown neutral images of faces. Later, people were better able to remember answers to questions that had stoked their curiosity—and, oddly, they were also more likely to recall faces that were paired with those questions. The brain imaging revealed increased activity in the hippocampus, critical to creating memories. Matthias Gruber of Cardiff University in Wales, lead author on that study, has called curiosity "a vortex" that pulls in not just what you wanted to know about but incidental information around it.

Anyone who's been subjected to their barrage of "why" questions knows that children possess powerful curiosity. The rudimentary elements of their curious brain circuits seem to be present early. Studying curiosity in babies shows how these circuits are already poised to guide knowledge acquisition throughout life, according to Kidd. Babies are driven to maximize learning from their environment and seem to recognize that surprising events represent an opportunity. They show a strong preference for highly informative stimuli—a human face is more appealing than a toy truck, and infant-directed speech is more alluring than nonhuman sounds. Babies are also intrigued by anything new. Even babies who can't speak yet are aware of gaps in their knowledge. And Kidd has found that when children are uncertain, they continue to try to learn more and to store what they learn. Once they feel they understand something, they lose interest.

In an influential 2012 study, Kidd and her colleagues showed seven- to eight-month-old infants animated scenes of objects popping out of boxes. She used an eye tracker to measure how long the scenes engaged the babies' attention and found they preferred to look at scenes with an intermediate level of complexity. Not too predictable and a little bit surprising proved to be just right. (The researchers called it the "Goldilocks Effect.") In a 2022 paper, Kidd and her colleagues observed the same preference for intermediate complexity in monkeys, suggesting it is widespread.

The appeal of information of intermediate complexity—carrying just the right level of intrigue—makes sense as grist for the learning mill. It seems to represent an opportunity to add to what we know in accessible ways. To test the idea that learning progress is a piece of the curiosity puzzle, Oudeyer took the unusual step of bringing curiosity to computers. "Building machines that are curious was exotic and strange 20 years ago," he says. But it can be an efficient way to tackle big challenges, maybe even as big as getting to another planet someday.

Computers, of course, are not curious beings; they are compilations of wires, motors and sensors. In 2016, when Google DeepMind made headlines by building a computer that beat an 18-time world titleholder at the complex Chinese game Go, that computer still relied on a cutting-edge search capability and data fed into it about possible moves. But as people improved at building AI, they started asking whether there was a better way to have computers learn complicated things. One answer would be to give them curiosity—or programming that mimics the thought patterns behind curiosity-driven exploration. That's just what Oudeyer and his colleagues did.

Torso the robot has a blue head, blue arms and a blue upper body attached to a wood base, and it is programmed to explore its surroundings as a child would. It learns how objects interact by playing with them. Two joysticks are mounted to Torso's base. On a coffee table, a circular, rimmed arena ringed with lights contains a tennis ball and a smaller robot called Ergo, which looks like a chunky desk lamp.

Unlike humans and other animals, robots can be programmed to model the behavior of an ideal agent and test popular theories of how we explore. Do we keep track of prediction errors—that is, how right or wrong our guesses about outcomes are? Yes, but a robot programmed to do only that was distracted by its own movements in irrelevant ways (imagine waving repeatedly in front of a window to learn how each arm movement relates to the color of the cars going by outside). Do we zero in on novelty or uncertainty? Yes, but absent other motivations, those led to random and disorganized behavior in machines.

Torso learned fastest and most efficiently when programmed to pursue curiosity. The robot could produce movements and perceive its environment and was instructed to find correlations between the two, though without specific aims. Instead Torso was to search for opportunities for learning and follow where they led. “He’s basically told, your only goal is to try to find goals for which you are making progress,” Oudeyer says. In effect, as Torso gains knowledge, it is saying something like, *Hmm, that’s interesting, let’s build on that*. It is the algorithmic version of reinforcement learning, or practicing. “A child needs to practice to be able to learn,” Oudeyer says. “What makes it practice? Its motivational system. Curiosity is one of the fundamental dimensions of motivational systems that push organisms to explore and to learn new things.”

When programmed this way, Torso first moved its left hand—a lot. Then it discovered the left joystick and moved it forward, backward, left and right. Eventually it made the connection between moving the joystick and moving Ergo, which moved the ball. Moving the ball changed the color of the lights from blue to yellow to pink. After 15 to 20 hours of exploration, Torso worked out how to move Ergo in every direction, how to move the ball and how to light up the arena. To the researchers’ surprise, the robot even worked out that the cup at the end of Ergo’s lamplike arm could cover the ball and effectively hide it, which Torso proceeded to do, looking an awful lot like a shell-game hustler working a crowd on the sidewalk.

Such experiments are evidence for a positive feedback loop between curiosity and learning. “Focus on learning activities that are neither too easy nor too difficult, the ones where you have maximum improvement in speed, which will progressively get you to more and more complicated and yet learnable activities,” Oudeyer says.

Torso’s progress closely mirrored the developmental trajectories children use as they learn about tools or language. As the brain continues to develop, so does the sophistication of its approach to curiosity. A 2024 study of more than 100 four-year-olds found that they relied on learning progress as well as novelty to explore during a touchscreen game. And Gruber has found that compared with younger children, adolescents are better able to process cognitive conflict (that is, uncertainty) and appraise incoming information in the higher-order areas of the prefrontal cortex.

As for adult humans, we hang out in a sweet spot, Kidd says. “We’re much more invested in watching more episodes of a show where we know the characters [and] understand something about the plot than starting something entirely new,” she says. Even in studies where participants get paid to be curious, their brains aren’t very curious about things that fall outside this satisfying mental place. But when they are deeply engaged, in what’s sometimes called a state of flow, learning progress is guiding them. It clearly feeds their curiosity.

In a 2021 experiment published in *Nature Communications,* Oudeyer and Gottlieb, who are frequent collaborators, and their colleagues created a set of four online games. Each game had families of monsters that varied in size, color, number of eyes, and so on. The goal? Discover the hidden rules that dictate which of eight foods each family of monsters likes to eat. The easiest game had a one-dimensional rule: tall family members like pizza, and short ones like broccoli. Two more games had progressively more complicated rules that were harder to pick up on: with two dimensions, for instance, tall monsters with three eyes like pizza, and short monsters with two eyes like broccoli. The fourth game had no rule; it was entirely random and unlearnable.

The question was how the nearly 400 players would organize their exploration as they worked out the rules. How could they be both curious and efficient? Correct guesses are rewarding, and errors are instructive, but do people monitor how much they are learning and use that information to decide what to do next? In this case, yes, they did. Participants monitored both their percentage of correct responses and their improvement over time. “It becomes obvious that what we should value is learning,” Gottlieb says. In other words, high certainty alone is less useful than the transition between high and low uncertainty. Curiosity is what helps us make that shift.

But curiosity also shifts over time. Although conventional wisdom says people get less curious as they grow older, studies show that it’s more accurate to say curiosity adapts to what people know about the world. When you walk into the Louvre in Paris, are you more likely to swing through all the galleries, making sure to hit the most popular exhibits? Or do you prefer to lose yourself for an hour in one wing? Your choice most likely will depend on your age, Tübingen’s Murayama says. In an experiment conducted with almost 500 visitors to the London Science Museum who were aged 12 to 79, he found younger people took a broad approach and older people a narrower but deeper approach, viewing more facts on fewer topics in a citizen science exhibit. “Older adults have more knowledge, and knowledge is really a driver of curiosity.”

As scientists come to understand curiosity better, they may also better understand some mental health disorders in which its circuits may be disrupted. In depression, for example, curiosity is dampened, whereas in obsessive-compulsive disorder the desire to reduce uncertainty is overwhelming.

The research has more immediate implications in the classroom. It's well known that curiosity has a positive influence on learning outcomes and student enjoyment. Multiple efforts are underway to leverage the new findings to strengthen both things. In 2024 the French government began giving primary school students a peer-reviewed educational technology based on Oudeyer's work. The program generates personalized questions driven by what each child wants to learn. Compared with material that teachers created by hand, the AI-designed material led to more efficient learning and higher student motivation because they built on a child's own interests.

There may be useful ways to boost adult curiosity, too. Several researchers are working on programs based on learning progress that help older adults hone their attentional skills. But anyone can take advantage of the sweet spot, Kidd says. "Just even understanding that having some knowledge will make it easier to acquire more knowledge can be helpful," she says. It can get you to "sit and try to focus more on that first book that lets you break in" to a new subject.

And understanding that confidence and curiosity are related probably affected your level of curiosity about the nuggets of trivia I sprinkled through this story. Maybe you knew that the most popular exhibit at the Louvre is the *Mona Lisa* or guessed that the Beatles' most durable hit was *Hey*

Jude. But I suspect you were very curious about those odd-shaped trees. Yes, there really are trees with square trunks—in Anton Valley in Panama.

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No Spoilers, Please! Abby Hsiung, Jia-Hou Poh, Scott Huettel and Alison Adcock; September 2024. ScientificAmerican.com/archive

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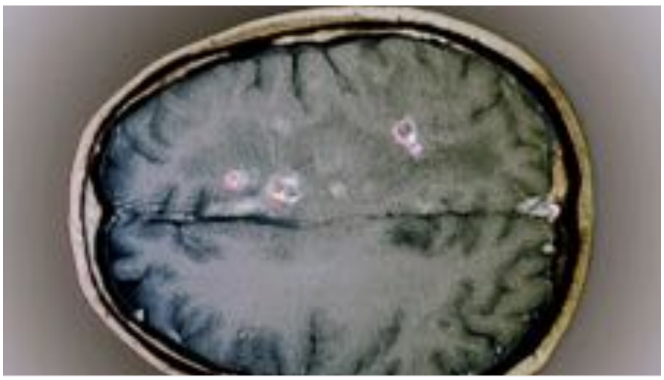

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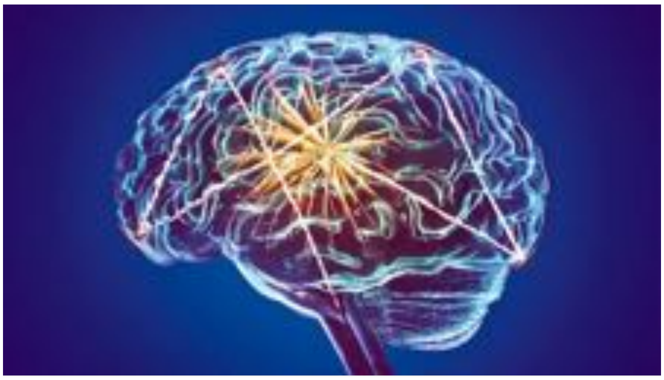

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