SPECIAL TIME EDITION

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A LIFETIME OF LEARNING

Our ability to acquire and access knowledge changes as we grow, constantly building an intricate web of information and ideas

By Jeffrey Kluger

YOU DIDN'T GET 100 BILLION BRAIN CELLS FOR NOTHING. You didn't get the three-pound, four-lobed, ugly but brilliant supercomputer that lives inside your head so it could just plod through its days like any other organ—repeatedly beating like the heart or expanding and contracting like the lungs or secreting this or that hormone on neurochemical demand like your glands. You got your brain to run all the systems, to manage the operation, to conduct the entire orchestral arrangement that is your body.

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And you got your brain to learn. And learn and learn and learn.

We're born knowing close to nothing. We know when we're hungry. We know when we're wet. We know that if we make very loud noises over and over, the giants who take care of us will suddenly appear, pick us up, work some magic and set things right again. We don't know exactly what or who the giants are, but we're born with the knowledge that a certain configuration of features represents eyes, a nose and a mouth (not that we know what eyes, noses and mouths do), and we're drawn to that pattern of shapes—so much so that we recognize it in plush toys or even line drawings.

It takes us longer to learn the basic physics of things—that objects we don't hold on to will fall. That when they do fall and we can no longer see them, they still exist. Failing to understand that idea—object permanence—is one of the reasons we may cry so pitiably when we are left alone. If the giant people we've come to recognize as our caregivers aren't in the room right now, they must have vanished forever.

It takes us longer still, often well into toddlerhood, to learn the secrets of thought—especially that all thought isn't universal thought, that just because you know something doesn't mean that other people do. This lack of a so-called theory of mind shows up in experiments in which a child and an adult experimenter will hide a toy together and the child will seem surprised that another experimenter who comes into the room a few minutes later doesn't know where the toy is. Doesn't everybody know?

We learn language or even multiple languages effortlessly in childhood—simply picking it up from the ether rather than relying on the brute-muscle work of drilling and redrilling lists of words and conjugations that adults must rely on when they try to master a tongue other than their native one.

We drink similarly easily from the firehose of knowledge that comes at us from the other parts of the world: we learn to manipulate objects, to master tools and utensils and crayons and pencils. We learn to write and to draw and to run and to dance and to play sports and to sing songs and on and on—and then, so it seems, one day all of the ease and frequency of learning comes to an end.

We become young adults and then not-so-young adults. We earn our degrees, learn a profession, choose a mate and maybe pick up a hobby or two, and the storm of information that was forever soaking into our brains from the outside world seems to bounce off instead. Why did they have to upgrade that app when we finally

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figured out how to use the last version? Why must there be a thousand buttons on the TV remote when we just know we'll wind up using only three or four of them? Why is the math our kids are learning so mystifying, so different from the math we learned? Since when did numbers themselves change their character?

It's at this point that we generally conclude that our days as a learner are over. Yes yes, if you practice, you can maybe pick up yet another hobby—painting or skiing or sailing perhaps. But it's slow going, requiring constant work and effort and a certain grim deliberateness. Where is the ease of learning that defined our childhoods?

Actually, it's still there—it's always been there—we just don't recognize it. Science has already dispensed with the notion that the adult brain is a more or less fixed thing, that its neurons can't grow and their connections can't stay nimble. They can. The brain of the stroke patient develops workarounds to bypass damaged tissue and restore function to, say, a partly paralyzed arm or leg. The brain of an aging person learns to apportion tasks—recruiting both hemispheres to handle work or process information that was taken care of by just one a few decades earlier when the brain was new and so was the world.

We learn patience and tolerance too. We see the world not in binary shades—good and bad, friend and enemy, red state or blue state. In the place of such an on-off digital system comes something more analog, something with shades of color, meaning and rightness and wrongness. Our morality may not change—we still know genuine good from genuine bad. But that theory of mind we learned so long ago—that not everyone knows where the toy is hidden—becomes a much more important thing and a much more powerful skill. I believe absolutely and immovably in my positions on this or that political or moral issue, but I can understand too why you don't agree, and if I'm willing to make an effort, I can try at least to see it the way you see it.

There's a reason it's young people who are firebrands and revolutionaries—and we need firebrands and revolutionaries sometimes. But there's also a reason that older people are judges, religious leaders and great statesmen and stateswomen. They have learned to use tools just like the child learned to use them—but they are tools of reason and compromise and negotiation. They have learned language just like babies do, but it is the language of empathy, understanding and cooperation.

There is a popular myth at large in the world—the 10,000-hour myth. Practice something for that length of time—the equivalent of 60 straight weeks—and you

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can become an expert at it. Maybe that's so for some things. The surgeon or the mechanic who performs 10,000 hours' worth of bypasses or engine repairs does become awfully good at the job. But it takes more than that to become a compassionate minister, an intuitive psychotherapist, or even a good parent or a faithful friend.

Learning is a lifetime enterprise. A constant process of feeding and tending and filling the brain you got at birth—a brain that was so empty back then, so full of potential but devoid of wisdom. At bottom, it's all neurochemistry: one insensible brain cell communicating with thousands of other insensible brain cells, forging connections and networks that eventually stir to life with insight and caring and awareness. Your brain is more than just the greatest natural computer on Earth. It's also the most exquisite pointillist painting ever created. Each dot—each brain cell—is nothing by itself. But assembled just so, artfully organized just so, it is a mindful masterpiece. The best part: you can keep adding dots—keep improving the picture—every day you're alive.

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Babies may not know much at birth, but they have an extraordinary ability to learn quickly.

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As we grow older, we are better able to consolidate and analyze our knowledge.

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THE WAYS WE LEARN

We spend our entire lifetimes experiencing the world around us and converting information into knowledge that we can put to use in our daily lives

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HARNESSING A UNIVERSE OF KNOWLEDGE

Research shows that a variety of factors—biological, emotional and environmental—help drive our ability to learn

By Markham Heid

To encourage learning, parents should take an active role in fostering a child's intellectual curiosity.

IN HIS 1974 BEST SELLER, *ZEN AND THE ART OF MOTORCYCLE MAINTENANCE*, the author Robert M. Pirsig describes an occasion when, in the middle of a rainstorm, his titular bike sputters to a stop and won't restart.

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Pirsig rocks the motorcycle from side to side and, hearing the sound of sloshing liquid, assumes that it still has gas in its tank. He spends time examining the bike's components—its plugs, points and carburetor—in a fruitless effort to identify the issue, which he assumes has to do with the rain. Eventually he gives up and hauls his bike back home on a trailer. Weeks later while reexamining the bike, he starts to take its engine apart and realizes that its gas tank is empty, which was the problem all along. The sloshing sound he'd heard was the gas in his reserve tank, which he'd never switched on.

What Pirsig describes is a quintessential learning experience. But what's the lesson? Some might say, "Always double-check the gas tank." And that's true. But Pirsig himself, on later reflection, views the experience as a cautionary tale about the dangers of assumption. The lesson he took from that day and tries to apply to future dilemmas—many of which have nothing to do with motorcycles—is that jumping to conclusions or working hastily leads to silly mistakes and unnecessary trials.

The blunder that Pirsig describes and the knowledge that he hopes to glean from it help illustrate the complexity of human learning—much of which is experience-based. How can people both lock away useful knowledge or wisdom and, just as important, summon it at the appropriate moment? These are the sorts of questions that challenge experts who study the science of learning.

"Learning is a very active process—not one of 'ingesting and retaining' like a squirrel ingests nuts or a file drawer stores information," says Mary Helen Immordino-Yang, a professor of education, psychology and neuroscience at the University of Southern California's Rossier School of Education. Life exposes the brain to a limitless ocean of information. Even if a person manages to memorize a portion of it—to squirrel it away—it does them little good unless they can access it at the right moment and apply it in real-world contexts. "The task of learning is to transform some of that information into knowledge that can be used and acted upon," she says.

Learning is among the brain's fundamental functions. The question "How does the brain learn?" is roughly analogous to "How does the brain work?" There is no simple answer. Learning could mean sitting down with a textbook to study algebra or the law. But the rush of dopamine-fueled pleasure that the brain experiences when a person takes a bite of ice cream or taps one of the candy-colored icons on a smartphone is also a form of learning. So is the memory of a mistake—such as the

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one Pirsig describes—that teaches a person to be patient and deliberate.

As the saying goes, "live and learn." But life's teachings are often nested inside one another. How does the brain sort through and soak up these coincident lessons? Why do some people thrive in certain learning contexts while others flounder? And what are the factors, both internal and external, that help people retain and recall knowledge in ways that will be most helpful to them? Researchers say some of those questions have clear answers. Others remain clouded in debate.

Learning: The Necessary Ingredients

One of the simplest ways to approach the science of learning is to examine the skills or characteristics that facilitate learning in a range of contexts. What tools does the brain require to do the work of learning? While the list is long, experts say some are clearly more essential than others.

"Motivation, or a willingness to learn, is one of the basic elements," says Eva Kyndt, an associate professor at the University of Antwerp in Belgium and Swinburne University of Technology Melbourne in Australia. Kyndt says that motivation often comes when the brain takes note of a "discrepancy"—a disconnect between the knowledge it has and the knowledge it wants. This discrepancy may be positive or negative. "It could be, 'Damn it, I have a problem to solve and I don't have the skills to solve it,' " she says. "Or it could be, 'That's really interesting, and I want to know more about that.' " The brain doesn't hold on to information arbitrarily; it keeps what it believes it can use.

One way to motivate the brain is to expose it to something new and unfamiliar. Kyndt's current area of research concerns professional development and continuing education. She says that when people start a new job, their lack of knowledge is so apparent to them that motivation often arises naturally. But as people spend years or decades in a role, their motivation to learn often falls. For companies hoping to encourage these less-motivated employees, showing them the holes in their knowledge can be helpful. "It used to be that you'd train people and then test them on their knowledge," says Kyndt. "Now some organizations are starting with testing to show people the discrepancy that exists and the value they'd get out of [addressing] it."

Another aspect of learning—one that goes hand in hand with motivation—is opportunity. "If you're very highly motivated, you'll create your own opportunities,"

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Kyndt says. “But if the opportunities are there and easy, you may need less motivation.” For example, a young person who has access to private tutoring or other educational resources may require less motivation to learn than the student who lacks access to such tools and aids.

Along with motivation and opportunity, sustained attention is another important learning skill. “The ability to learn new things—whether that’s calculus or hitting a fast ball—requires stretching your brain past the point of what’s familiar or comfortable,” says Cal Newport, an associate professor of computer science at Georgetown University and the author of *Digital Minimalism*. “And that stretch requires unbroken concentration.” He says that the amount of concentration a person requires to learn something new depends in part on the complexity of the material. The more complex something is, the more sustained focus a person will likely need to grasp it.

There are other skills or “habits of mind” that facilitate learning, such as curiosity and diligence. And the published scholarship on learning is packed with papers that explore the ways in which a person can cultivate or corrupt these skills. But where do these capabilities come from to begin with? Why do some people seem to possess a large measure of them innately while others do not? Experts say a person’s experience, age and environment help explain why learning comes easily to some and not to others.

Teaching a Mind to Learn

Is an ability to learn written into a person’s genetic code? Maybe, at least a little bit. Research from the University of Texas at Austin has found evidence that genes play a part in shaping a person’s character traits, including some—such as intellectual curiosity—that are associated with academic achievement.

But researchers have thus far identified more than 800 genes that are associated with cognitive functioning. How clusters of these genes interact with one another and are expressed and how all that promotes or inhibits learning in a given individual or situation are puzzles that science is unlikely to solve. “Genes may explain some percentage of a person’s ability to learn, but the work there is very unsatisfying,” says Charles Nelson III, a professor of pediatrics and neuroscience at Harvard Medical School and a professor of education at Harvard University.

Setting aside the role of genetics, Nelson says that a more useful question—and

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one that researchers are closer to answering—pertains to the childhood environments and relationships that set people up for a lifetime of learning. "The home environment seems to matter," he says. "Children who grow up in cognitively stimulating and linguistically rich environments tend to be more sophisticated in their knowledge of the world and their ability to grasp things." What does "cognitively stimulating" mean in this context? "Playing games with kids," he says. "Interacting with them and challenging them intellectually." This kind of challenging interaction could be as simple as asking children thoughtful questions, pushing them to solve their own problems or teaching them numbers and letters. "The contrast to this," he says, "would be plopping the kid in front of a screen or a TV and not talking to them." Screens are fine in small doses, he adds, but human interaction seems to be the best fertilizer for growing a healthy, inquisitive and capable mind.

While many parents rightly focus on the quality of their children's schools, experts say that early childhood may matter just as much—or even more—when it comes to shaping the kinds of brains that learn best. "We've known for years that there's this explosion of brain development during the first three years [of childhood], but as a society we don't invest much in these years in relation to what we spend on kindergarten through 12th grade," says Doug Knecht, a former teacher and current vice president of Bank Street College of Education, a higher-education institution in New York City. Unlike most other developed countries, the U.S. allocates very little money to the subsidy of high-quality day-care and preschool services—a situation that Knecht calls "shameful" and counterproductive.

There has been—and continues to be—a tremendous amount of attention paid to K–12 education and the different teaching styles, curricula and school environments that best support learning. There is not broad expert consensus on these topics, but some say change is needed. "There's a lot of evidence that project-based learning has a better impact on student learning and readiness for life after high school," Knecht says. He's referring to a program of education that eschews traditional teach-and-test methods in favor of immersive lessons that challenge students with problems or scenarios that promote self-directed investigation, critical thinking, creativity and teamwork.

Others agree that the ways in which traditional schools engage young minds are not ideal. "Schools should not be about memorizing information because that's

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really not how people learn," says USC's Immordino-Yang. Much of her work has focused on the ways that different methods of teaching build up and strengthen the connections among the brain networks that are involved in learning. She says that her research points to the benefits of educational programs that emphasize immersive and interest-driven learning experiences—the kind that present information in rich, real-life contexts and that engage more of young people's mental faculties, rather than just their ability to ingest and regurgitate information.

There's the old saw that people never remember what they learn in school. Immordino-Yang says this mostly misses the point of an education, which is not primarily about hammering facts, procedures and information into a person's memory; it's about building mental skills and dispositions that will help people learn and succeed throughout life. A 2020 study that she co-authored found that children educated in Montessori schools—which is one of several progressive approaches to education that prioritize independent exploration and problem solving—had different patterns of behavior and brain activity than kids educated in traditional schools. "Montessori students were more effective at directing their own learning, and by adolescence were much faster and more likely to correct their own mistakes," she says. When they got things wrong, the Montessori kids also seemed less distressed and more curious to figure out why. "They seemed more comfortable with not knowing things—with uncertainty and ambiguity," she says. These are characteristics that seem to correlate with improved learning at any age, she adds.

While it's often said that the older people get, the more they struggle to learn—you can't teach an old dog new tricks—the capacity to build new skills and knowledge tends to persist even as a person ages. "There's a certain tipping point around age 40 and 45 when some cognitive capacities—like working memory and attention span—slowly start to diminish," says the University of Antwerp's Kyndt. "But it's not dramatic. It's not to the extent that if you were a good learner as a kid, you're inept as an adult."

Kyndt says that the bigger learning hurdle for adults may be a lack of what Stanford University psychologist Carol Dweck has termed a "growth mindset"—or a belief that one's abilities and knowledge are capable of evolving. "Learning is often hard, and it takes time and effort," Kyndt says. "Those who believe everything is set in stone are less likely to undertake learning activities or to put in that time and effort." In other words, the ability to learn is often still there, assuming a person had

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it as a youngster; it's the self-confidence that falters.

What's Next

In a 2018 report for the Aspen Institute, a nonprofit think tank, Immordino-Yang and her co-authors write, "Just as a garden grows differently in different climates and with different plants, styles of gardening and use, a person's brain develops differently depending on age, predispositions, priorities, experiences and environment."

Development and learning are inextricably knotted, she says. And there is not a single formula or recipe that produces the sort of brain that is optimized for all types of learning in all contexts. On top of the many variables mentioned above, a person's overall health—a proper diet, as well as adequate sleep and regular exercise—affects brain functioning and learning. So does the presence or absence of trauma in a person's life. "The quality of our social relationships also matters," Immordino-Yang says. "And having a sense of purpose across the life span matters."

She and others in her field are identifying what seem to be some of the core ingredients that, especially early in life, promote a durable willingness and ability to learn. But there's a lot left to be discovered.

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Games and puzzles can help build an aptitude for finding solutions to complex problems.

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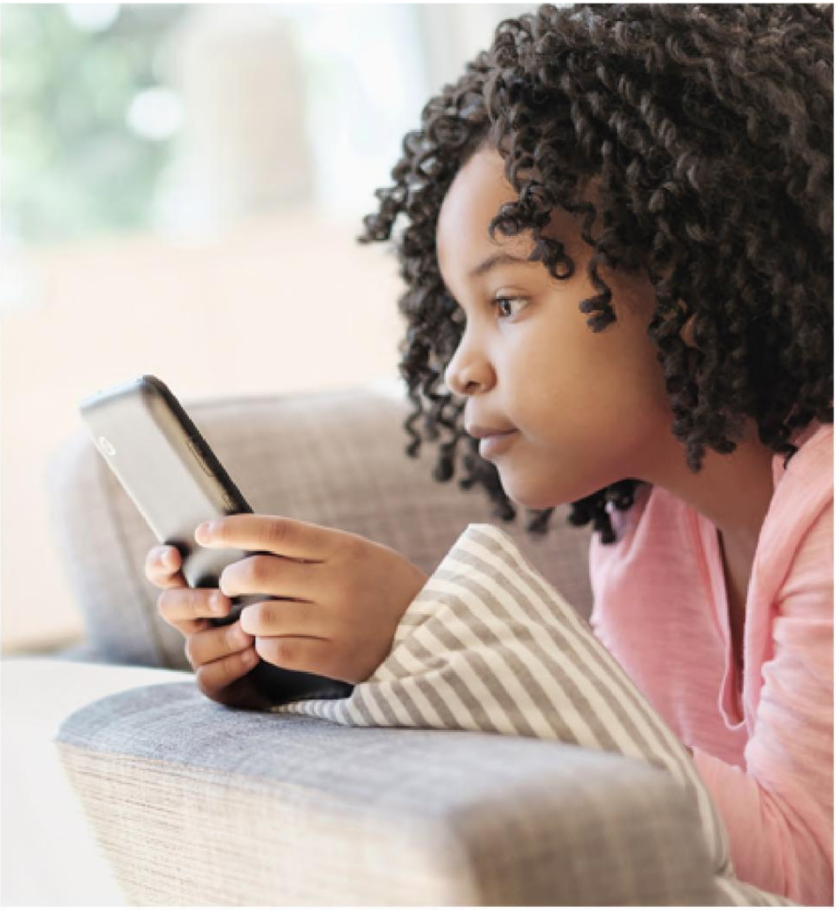

Students comfortable with independent study are often confident in the face of setbacks.

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Even as we age, we can develop new areas of expertise, especially with an open-minded attitude.

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THE SECRET BRAINPOWER OF BABIES

Almost immediately after birth, infants have the capacity to begin understanding the world around them

By Stanislas Dehaene

Babies quickly comprehend the laws of physics, and they're fascinated by objects that defy those laws (like floating balloons).

ON THE SURFACE, WHAT COULD BE MORE DESTITUTE OF KNOWLEDGE than a newborn? What could be more reasonable than to think, as Locke did, that the infant's mind is a "blank slate" simply waiting for the environment to fill its empty pages? Jean-Jacques Rousseau (1712–78) strove to drive this point home in his treatise *Emile, or On Education* (1762): "We are born capable of learning, but knowing nothing, perceiving nothing." Almost two centuries later, Alan Turing, the father of contemporary computer science, took up

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the hypothesis: "Presumably the child brain is something like a notebook as one buys it from the stationer's. Rather little mechanism, and lots of blank sheets."

We now know that this view is dead wrong—nothing could be further from the truth. Appearances can be deceiving: despite its immaturity, the nascent brain already possesses considerable knowledge inherited from its long evolutionary history. For the most part, however, this knowledge remains invisible, because it does not show in babies' primitive behavior. It therefore took cognitive scientists much ingenuity and significant methodological advances in order to expose the vast repertoire of abilities all babies are born with. Objects, numbers, probabilities, faces, language . . . the scope of babies' prior knowledge is extensive.

The Object Concept

We all have the intuition that the world is made of rigid objects. In reality, it is made up of atoms, but at the scale on which we live, these atoms are often packed together into coherent entities that move as a single blob and sometimes collide without losing their cohesiveness. These large bundles of atoms are what we call "objects." The existence of objects is a fundamental property of our environment. Is this something that we need to learn? No. Millions of years of evolution seem to have engraved this knowledge into the very core of our brains. As early as a few months of age, a baby already knows that the world is made up of objects that move coherently, occupy space, do not vanish without reason and cannot be in two different places at the same time. In a sense, babies' brains already know the laws of physics: they expect the trajectory of an object to be continuous in space as in time, without any sudden jump or disappearance.

How do we know this? Because babies act surprised in certain experimental situations that violate the laws of physics. In today's cognitive-science laboratories, experimenters have become magicians. In small theaters specially designed for babies, they play all sorts of tricks: on the stage, objects appear, disappear, multiply, pass through walls. Hidden cameras monitor the babies' gazes, and the results are clear-cut: even babies a few weeks old are sensitive to magic. They already possess deep intuitions of the physical world and, like all of us, are stunned when their expectations turn out to be false. By zooming in on the children's eyes—to determine where they look and for how long—cognitive scientists manage to accurately measure their degree of surprise and infer what they expected to see.

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Hide an object behind a book, then suddenly crush it flat, as if the hidden object no longer existed (in reality, it escaped through a trapdoor): babies are flabbergasted! They fail to understand that a solid object can vanish into thin air. They appear dumbfounded when an object disappears behind one screen and reappears behind another, without ever being seen in the empty space between the two screens.

Babies therefore possess a vast knowledge of the world, but they don't know everything from the start, far from it. It takes a few months for babies to understand how two objects can support each other. At first, they don't know that an object falls when you drop it. Only very gradually do they become aware of all the factors that make an object fall or stay put. First, they realize that objects fall when they lose their support, but they think that any sort of contact suffices to keep an object still —for example, when a toy is placed at the edge of a table. Progressively, they realize that the toy must not only be in contact with the table, but on top of it, not under or against it. Finally, it takes them a few more months to figure out that this rule is not enough: in the end, it's the center of gravity of the object that must remain above the table.

Keep this in mind the next time your baby drops his or her spoon from the table for the 10th time, to your great despair: they are only experimenting!

This experimental attitude continues all the way into adulthood. We are all fascinated with gadgets that seem to violate the usual laws of physics (helium balloons, mobiles in equilibrium, roly-poly toys with a displaced center of gravity . . .), and we all enjoy magic shows where rabbits disappear in a hat and women are sawed in two. These situations entertain us because they violate the intuitions that our brain has held since birth and refined in our first year of life. Josh Tenenbaum, a professor of artificial intelligence and cognitive science at MIT, hypothesizes that babies' brains host a game engine, a mental simulation of the typical behavior of objects similar to the ones that video games use in order to simulate different virtual realities. By running these simulations in their heads and by comparing simulations with reality, babies discover very early on what is physically possible or probable.

The Number Sense

Let's take a second example: arithmetic. What could be more obvious than that babies have no understanding of mathematics? And yet, since the 1980s,

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experiments have shown quite the opposite. In one experiment, babies are repeatedly presented with slides showing two objects. After a while, they get bored . . . until they are shown a picture with three objects: suddenly, they stare longer at this new scene, indicating that they detected the change. By manipulating the nature, size and density of objects, one can prove that children are genuinely sensitive to the number itself, i.e., the cardinal of the whole set, not another physical parameter. The best proof that infants possess an abstract "number sense" is that they generalize from sounds to images: if they hear tu tu tu tu—that is, four sounds—they are more interested in a picture that has a matching number of four objects in it than in a picture that has 12, and vice versa. Well-controlled experiments of this sort abound and convincingly show that, at birth, babies already possess the intuitive ability to recognize an approximate number without counting, regardless of whether the information is heard or seen.

Can babies calculate too? Suppose that children see an object hide behind a screen, followed by a second one. The screen then lowers—lo and behold, only one object is there! Babies manifest their surprise in a prolonged investigation of the unexpected scene. If, however, they see the two expected objects, they look at them for only a brief moment. This behavior of "cognitive surprise," in reaction to the violation of a mental calculation, shows that, as early as a few months of age, children understand that 1 + 1 should make 2. They build an internal model of the hidden scene and know how to manipulate it by adding or removing objects. And such experiments work not only for 1 + 1 and 2 – 1, but also for 5 + 5 and 10 – 5. Provided that the error is big enough, 9-month-old babies are surprised whenever a concrete display hints at a wrong calculation: they can tell that 5 + 5 cannot be 5, and that 10 – 5 cannot be 10.

Is this really an innate skill? Could the first months of life suffice for a child to learn the behavior of sets of objects? While children undoubtedly refine the accuracy with which they perceive numbers over the first months of life, the data show, equally clearly, that the starting point for children is not a blank slate. Newborns perceive numbers within a few hours of life—and so do monkeys, pigeons, ravens, chicks, fish and even salamanders. And with the chicks, the experimenters controlled all the sensory inputs, making sure that the baby chicks did not see even a single object after they hatched . . . yet the chicks recognized numbers.

Such experiments show that arithmetic is one of the innate skills that evolution

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bestows unto us, as well as many other species.

Incidentally, these results overturn several tenets of a central theory of child development, that of the great Swiss psychologist Jean Piaget (1896–1980). Piaget thought that young infants were not endowed with "object permanence"—the fact that objects continue to exist when they are no longer seen—until the end of the first year of life. He also thought that the abstract concept of number was beyond children's grasp for the first few years of life, and that they slowly learned it by progressively abstracting away from the more concrete measures of size, length and density. In reality, the opposite is true. Concepts of objects and numbers are fundamental features of our thoughts; they are part of the "core knowledge" with which we come into the world, and when combined, they enable us to formulate more complex thoughts.

Concepts of objects and numbers are part of the "core knowledge" with which we come into the world, and when combined, they enable us to formulate more complex thoughts.

Number sense is only one example of what I call infants' invisible knowledge: the intuitions that they possess from birth and that guide their subsequent learning. Here are more examples of the skills researchers have demonstrated in babies as young as a few weeks old.

The Intuition of Probabilities

Going from numbers to probabilities takes only one step . . . a step that researchers have recently taken by wondering if babies a few months old could predict the outcome of a lottery draw. In this experiment, babies are first presented with a transparent box containing balls that move around randomly. There are four balls: three red and one green. At the bottom, there is an exit. At some point, the container is occluded, and then either a green ball or a red ball comes out the bottom. Remarkably, the child's surprise is directly related to the improbability of what she sees: if a red ball comes out—the most likely event, since the majority of the balls in the box are red—the baby looks at it for only a brief moment . . . whereas if the more improbable outcome occurs, that is, a green ball that had only one chance in four to come out, the baby looks at it for much longer.

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Subsequent controls confirm that babies run, in their little heads, a detailed mental simulation of the situation and the associated probabilities. Thus, if we introduce a partition that blocks the balls, or if we move the balls closer to or farther away from the exit, or if we vary the time before the balls exit the box, we find that infants integrate all these parameters into their mental calculation of probability. The duration of their gaze always reflects the improbability of the observed situation, which they seem to compute based on the number of objects involved.

From birth on, thus, our brain is already endowed with an intuitive logic. There are now many variations of those basic experiments. They all demonstrate the extent to which children behave like budding scientists who reason like good statisticians, eliminating the least likely hypotheses and searching for the hidden causes of various phenomena.

Knowledge of Animals and People

While babies have a good model of the behavior of inanimate objects, they also know that there is another category of entities that behave entirely differently: animate things. From the first year of life, babies understand that animals and people have a specific behavior: they are autonomous and driven by their own movements. Therefore, they do not have to wait for another object to bump into them, like a pool ball, in order to move around. Their movement is motivated from within, not caused from the outside.

Babies are therefore not surprised to see animals move by themselves. In fact, for them, any object that moves by itself, even if it is in the shape of a triangle or a square, is immediately labeled as an "animal," and from that moment on, everything changes. A small child knows that living beings do not have to move according to the laws of physics but that their movements are governed by their intentions and beliefs.

Let us take an example: if we show babies a sphere that moves in a straight line, jumps over a wall, then heads to the right, little by little, they will get bored of it. Are they simply getting used to this peculiar motion? No, in fact, they understand much more. They deduce that this is an animate being with a specific intention: it wants to move to the right! Moreover, they can tell the object is highly motivated, because it jumps over a high wall in order to get there. Now let's remove the wall. In this scenario, babies are not surprised if they see the sphere change its motion and move

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to the right in a straight line, without jumping—this is simply the best way to attain its goal. On the other hand, babies open their eyes wide if the sphere continues to jump in the air for no particular reason, since the wall has vanished! In the absence of a wall, the same trajectory as in the first scenario leaves the babies surprised, because they do not understand what strange intention the sphere might have. Other experiments show that children routinely infer people's intentions and preferences. In particular, they understand that the higher the wall is, the greater the person's motivation must be in order to jump over it. From their observations, babies can infer not only the goals and intentions of those around them, but also their beliefs, abilities and preferences.

Face Perception

One of the earliest manifestations of infants' social skills is the perception of faces. For adults, the slightest hint suffices to trigger the perception of a face: a cartoon, a smiley, a mask. Some people even detect the face of Jesus Christ in the snow or on burnt toast! Remarkably, this hypersensitivity to faces is already present at birth: a baby a few hours old turns its head more quickly to a smiley face than to a similar image turned upside down (even if the experimenter ensures that the newborn has never had the chance to see a face).

Many researchers believe that this magnetic attraction to faces plays an essential role in the early development of attachment—especially since one of the earliest symptoms of autism is avoiding eye contact. By attracting our eyes to faces, an innate bias would force us to learn to recognize them—and indeed, as early as a couple of months after birth, a region of the visual cortex of the right hemisphere begins to respond to faces more than to other images, such as places. The specialization for faces is one of the best examples of the harmonious collaboration between nature and nurture. In this domain, babies exhibit strictly innate skills (a magnetic attraction to face-like pictures), but also an extraordinary instinct to learn the specifics of face perception. It is precisely the combination of these two factors that allows babies, in a little less than a year, to go beyond naively reacting to the mere presence of two eyes and a mouth and to start preferring human faces to those of other primates, such as monkeys and chimpanzees.

The Language Instinct

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The social skills of small children are manifest not only in vision, but also in the auditory domain—spoken language comes to them just as easily as face perception. As Steven Pinker famously noted in his best-selling book *The Language Instinct* (1994), "Humans are so innately hardwired for language that they can no more suppress their ability to learn and use language than they can suppress the instinct to pull a hand back from a hot surface." This statement should not be misunderstood: obviously, babies are not born with a full-blown lexicon and grammar, but they possess a remarkable capacity to acquire them in record time. What is hardwired in them is not so much language itself as the ability to acquire it.

Much evidence now confirms this early insight. Right from birth, babies already prefer listening to their native language rather than to a foreign one—a truly extraordinary finding which implies that language learning starts in utero. In fact, by the third trimester of pregnancy, the fetus is already able to hear. The melody of language, filtered through the uterine wall, passes on to babies, and they begin to memorize it. "As soon as the sound of your greeting reached my ears, the baby in my womb leaped for joy," said the pregnant Elizabeth when Mary visited her (as told in Luke 1:44). The Evangelist was not mistaken: in the last few months of pregnancy, the growing fetus's brain already recognizes certain auditory patterns and melodies, probably unconsciously.

It was long thought that language acquisition does not begin until one or two years of age. Why? Because—as its Latin name, *infans,* suggests—a newborn child does not speak and therefore hides its talents. And yet, in terms of language comprehension, a baby's brain is a true statistical genius. To show this, scientists had to deploy a whole panoply of original methods, including the measurement of infants' preferences for speech and non-speech stimuli, their responses to change, the recording of their brain signals. These studies gave converging results and revealed how much infants already know about language. Right at birth, babies can tell the difference between most vowels and consonants in every language in the world.

But that's not all: babies quickly start to learn their first words. How do they go about identifying them? First, babies rely on prosody, the rhythm and intonation of speech—the way our voices rise, fall or stop, thus marking the boundaries between words and sentences. Another mechanism identifies which speech sounds follow each other. Again, babies behave like budding statisticians. They realize, for

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example, that the syllable /bo/ is often followed by /t^l/. A quick calculation of probabilities tells them that this cannot be due to chance: /t^l/ follows /bo/ with too high a probability; these syllables must form a word, "bottle"—and this is how this word is added to the child's vocabulary and can later be related to a specific object or concept. As early as six months of age, children have already extracted the words that recur with a high frequency in their environment, such as "baby," "daddy," "mommy," "bottle," "foot," "drink," "diaper" and so forth. These words become engraved in their memory to such an extent that, as adults, they continue to hold a special status and are processed more effectively than other words of comparable meaning, sound and frequency acquired later in life.

By the time they blow out their first candle, they have already laid down the foundation for the main rules of their native language at several levels, from elementary sounds (phonemes) to melody (prosody), vocabulary (lexicon) and grammar rules (syntax).

No other primate species is capable of such abilities. This very experiment has been attempted many times: several scientists tried adopting baby chimpanzees, treating them like family members, speaking to them in English or sign language or with visual symbols, only to find out, a few years later, that none of these animals mastered a language worthy of the name: they knew, at most, a few hundred words. The linguist Noam Chomsky, therefore, was probably right in postulating that our species is born with a "language acquisition device," a specialized system that is automatically triggered in the first years of life. As Darwin said in *The Descent of Man* (1871), language "certainly is not a true instinct, for every language has to be learnt," but it is "an instinctive tendency to acquire an art." What is innate in us is the instinct to learn any language—an instinct so irrepressible that language appears spontaneously within a few generations in humans deprived of it.

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As early as a few months of age, babies understand that the world is made up of objects with predictable behaviors.

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computer scientists of our time.” Gelernter’s 1991 book, *Mirror Worlds,* foretold with uncanny accuracy the ways the internet would reshape modern life, and his innovative software to arrange computer files by timeline rather than folder foreshadowed similar efforts by several major Silicon Valley firms. (A patent lawsuit against Apple was ultimately decided in Apple’s favor.) Yet Gelernter is not enthralled by the power of computer science, which he considers to be essentially a secular religion for its devoted disciples. His colleagues in computer science are so enamored of their own miraculous designs, he says, that they refuse to consider the limits of their machines.

Go back to that Gothic cathedral for a moment. How does it work its effects on the people who enter? In its scale and design, its vast weight and fortifying inspiration, its dark vaults and diffuse lights, in the ancient stories signaled through episodes of glass and carving, the church speaks to the mind of the engineer as well as the emotions of the pilgrim. The building can be measured and analyzed. But it is also felt. And how it feels depends on the time of day, the mental state of the visitor, the depth of the silence or the rumble of the organ. It smells of incense and age. It soars and it terrifies.

The human mind, Gelernter asserts, is not just a creation of thoughts and data; it is also a product of feelings. The mind emerges from a particular person’s experience of sensations, images and ideas. The memories of these sensations are worked and reworked over a lifetime, through conscious thinking and also in dreams. “The mind,” he says, “is in a particular body, and consciousness is the work of the whole body.”

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Engineers may build sophisticated robots, but they can’t build human bodies. And because the body—not just the brain—is part of consciousness, the mind alters with the body’s changes. A baby’s mind is different from a teenager’s, which is not the same as an elderly person’s. Feelings are involved (a lifetime of pain and elation go into the formation of a human mind). Loves, losses and longings. Visions. Scent, which was, to Proust, “the last vestige of the past, the best of it, the part which, after

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all our tears seem to have dried, can make us weep again.” Music, “heard so deeply/ That it is not heard at all, but you are the music/ While the music lasts,” as T.S. Eliot wrote. These are all physical experiences, felt by the body.

Moreover, Gelernter observes, the mind operates in different ways through the course of each given day. It works one way if the body is on high alert, another on the edge of sleep. Then, as the body slumbers, the mind slips entirely free to wander dreamscapes that are barely remembered, much less understood.

All of these physical conditions go into the formation and operation of a human mind, Gelernter says, adding, “Until you understand this, you don’t have a chance of building a fake mind.” Or to put it more provocatively (as Gelernter is prone to do): “We can’t have artificial intelligence until a computer can hallucinate.”

Gelernter’s book is the fruit of a lifetime’s reflection on such matters. Rejecting the analogy of brain to computer and mind to software as “childishly superficial,” he describes a variable human consciousness that operates along a spectrum from “high focus” to “low focus”—up and down, back and forth, many times each day.

At high focus, the mind works exactly like a computer. It identifies specific problems and tasks. It calls on the memory for data and patterns and instructions necessary to answer the questions and perform the jobs at hand. High focus finds the mind thinking about thinking; that is, thinking on purpose.

At low focus, the mind may drift, even seem to go blank. Notions and daydreams pop up without being consciously summoned. At the lowest focus, when the body is asleep, the dreaming mind churns up images and memories and patches them together—not according to a rational blueprint, Gelernter argues, but according to some sensation or emotion that they share.

“As we move down-spectrum,” he writes, “mental activity changes—from largely under control to out of control, from thinking on purpose to thought wandering off on its own. Up-spectrum, the mind pursues meaning by using logic. Moving down-spectrum, it tends to pursue meaning by inventing stories, as we try to do when we dream. A logical argument and a story are two ways of putting fragments in proper relationship and guessing where the whole sequence leads and how it gets there.”

Inevitably to modern, logical readers, this description suggests a hierarchy. “Up-spectrum” sounds superior to “down-spectrum,” “high focus” better than “low focus.” We might ask why artificial intelligence should not operate solely at high focus and up-spectrum. Leaving the lower range of consciousness behind might be

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