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A WORK IN PROGRESS

The Teen Brain

Your teenage daughter gets top marks in school, captains the debate team, and volunteers at a shelter for homeless people. But while driving the family car, she text-messages her best friend and rear-ends another vehicle.

How can teens be so clever, accomplished, and responsible—and reckless at the same time? Easily, according to two physicians at Children's Hospital Boston and Harvard Medical School (HMS) who have been exploring the unique structure and chemistry of the adolescent brain. "The teenage brain is not just an adult brain with fewer miles on it," says Frances E. Jensen, a professor of neurology. "It's a paradoxical time of development. These are people with very sharp brains, but they're not quite sure what to do with them."

Research during the past 10 years, powered by technology such as functional magnetic resonance imaging, has revealed that young brains have both fast-growing synapses and sections that remain unconnected. This leaves teens easily influenced by their environment and more prone to impulsive behavior, even without the impact of souped-up hormones and any genetic or family predispositions.

Most teenagers don't understand their mental hardwiring, so Jensen, whose laboratory research focuses on newborn-brain injury, and David K. Urion, an associate professor of neurology who treats children with cognitive impairments like autism and attention deficit disorder, are giving lectures at secondary schools and other likely places. They hope to inform students, parents, educators, and even fellow scientists about these new data, which have wide-ranging implications for how we teach, punish, and medically treat this age group. As Jensen told some 50 workshop attendees at Boston's Museum of Science in April, "This is the first generation of teenagers that has access to this information, and they need to understand some of their vulnerabilities."

Human and animal studies, Jensen and Urion note, have shown that the brain grows and changes continually in young people—and that it is only about 80 percent developed in adolescents. The largest part, the cortex, is divided into lobes that mature from back to front. The last section to connect is the frontal lobe, responsible for cognitive processes such as reasoning, planning, and judgment. Normally this mental merger is not completed until somewhere between ages 25 and 30—much later than these two neurologists were taught in medical school.

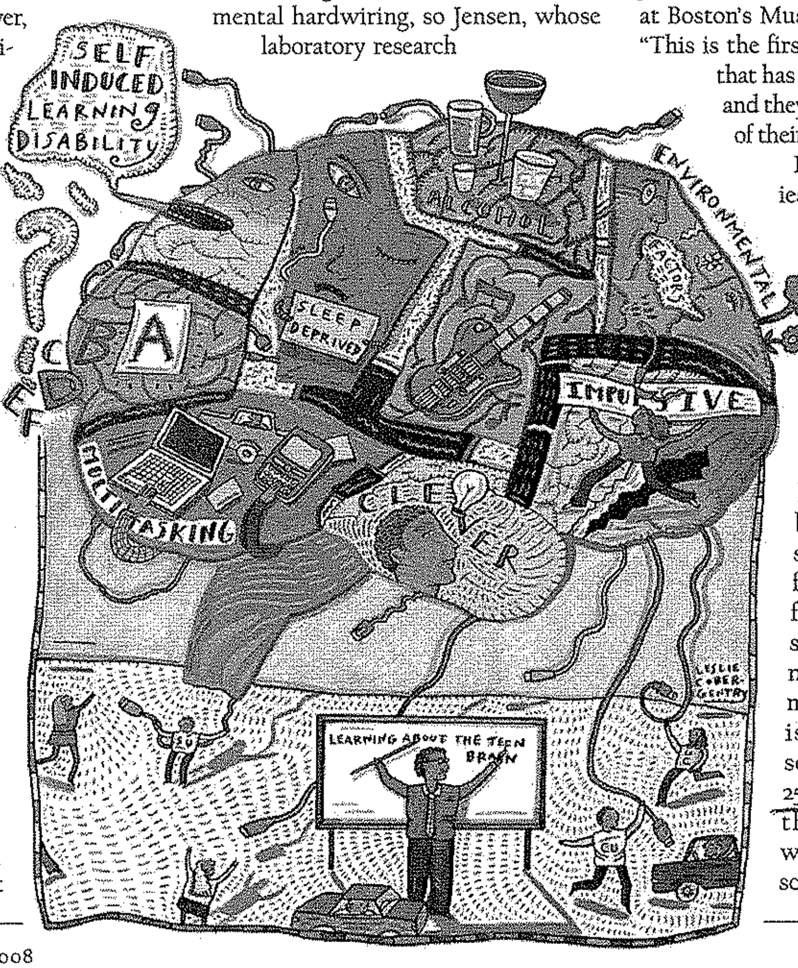
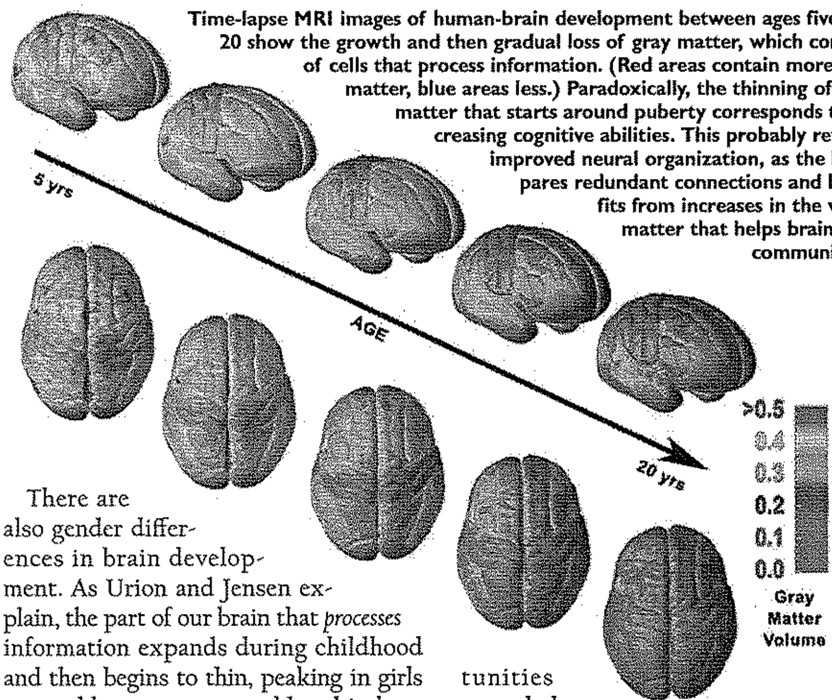


Illustration by Leslie Cober-Gentry



Time-lapse MRI images of human-brain development between ages five and 20 show the growth and then gradual loss of gray matter, which consists of cells that process information. (Red areas contain more gray matter, blue areas less.) Paradoxically, the thinning of gray matter that starts around puberty corresponds to increasing cognitive abilities. This probably reflects improved neural organization, as the brain pares redundant connections and benefits from increases in the white matter that helps brain cells communicate.

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There are also gender differences in brain development. As Urion and Jensen explain, the part of our brain that *processes* information expands during childhood and then begins to thin, peaking in girls at roughly 12 to 14 years old and in boys about two years later. This suggests that girls and boys may be ready to absorb challenging material at different stages, and that schools may be missing opportunities to reach them.

Meanwhile, the neural networks that help brain cells (neurons) communicate through chemical signals are enlarging in teen brains. Learning takes place at the synapses between neurons, as cells excite or inhibit one another and develop more robust synapses with repeated stimulation. This cellular excitement, or "long-term potentiation," enables children and teenagers to learn languages or musical instruments more easily than adults.

On the flip side, this plasticity also makes adolescent brains more vulnerable to external stressors, as Jensen and Urion point out.

Teen brains, for example, are more susceptible than their adult counterparts to alcohol-induced toxicity. Jensen highlights an experiment in which rat brain cells were exposed to alcohol, which blocks certain synaptic activity. When the alcohol was washed out, the adult cells recovered while the adolescent cells remained "disabled." And because studies show that marijuana (cannabinoid) use blocks cell signaling in the brain, according to Jensen, "We make the point that what you did on the weekend is still with you during that test on Thursday. You've been trying to study with a selfinduced learning disability."

Similarly, even though there is evidence that sleep is important for learning and memory, teenagers are notoriously sleep-deprived. Studying right before bedtime can help cement the information under review, Jensen notes. So can aerobic exercise, says Urion, bemoaning the current lack of physical-education opportunities for many American youths.

Teens are also bombarded by information in this electronic age, and multitasking is as routine as chatting with friends on line. But Jensen highlights a recent study showing how sensory overload can hinder undergraduates' ability to recall words. "It's truly a brave new world. Our brains, evolutionarily, have never been subjected to the amount of cognitive input that's coming at us," she says. "You can't close down the world. All you can do is educate kids to help them manage this." For his part, Urion believes programs aimed at preventing risky adolescent behaviors would be more effective if they offered practical strategies for making in-the-moment decisions, rather than merely lecturing teens about the behaviors themselves. ("I have yet to meet a pregnant teenager who didn't know biologically how this transpired," he says.)

By raising awareness of this paradoxical period in brain development, the neurologists hope to help young people cope with their challenges, as well as recognize their considerable strengths.

~DEBRA BRADLEY RUDER

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MYSTERIES OF MATH

Proof Positive

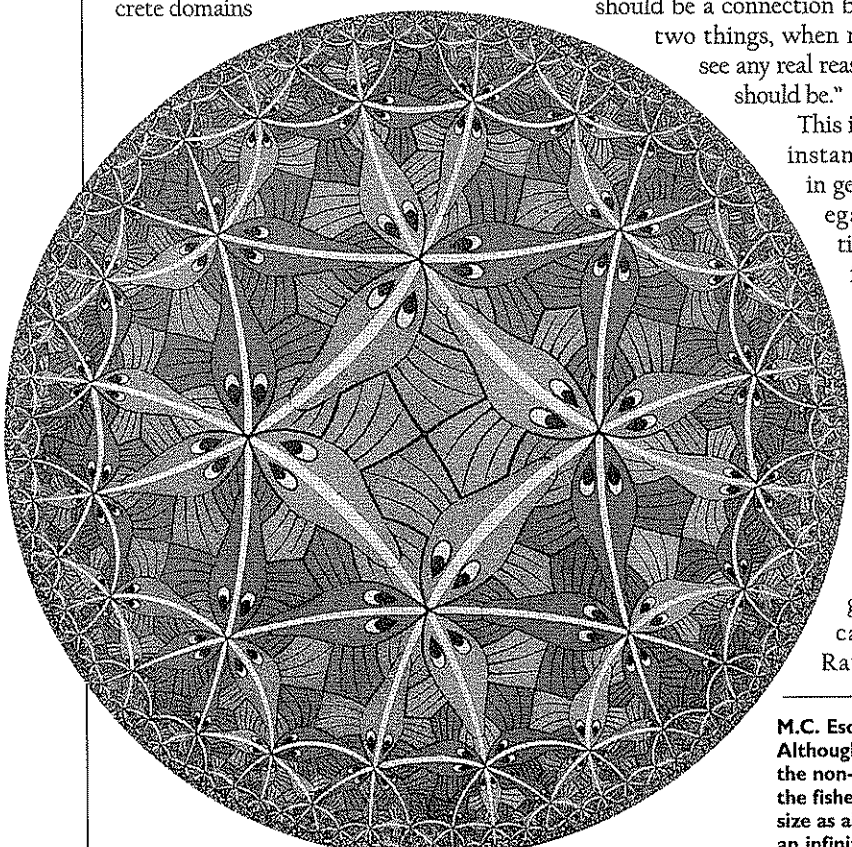
As ACADEMICS work to understand the architecture of the universe, they sometimes uncover connections in mysterious places. So it is with Smith professor of mathematics Richard L. Taylor, whose work connects two discrete domains of mathematics: curved spaces, from geometry, and modular arithmetic, which has to do with counting. Taylor has spent his career studying this nexus, and recently proved it is possible to use one domain to solve complex problems in the other. "It just astounded me," he says, "that there should be a connection between these two things, when nobody could see any real reason why there should be."

This is not the first instance of finding in geometry an elegant explanation for a seemingly unrelated phenomenon. Scholars during the Renaissance, seeking a mathematical basis for our conceptions of beauty, fingered the so-called Golden Ratio (approximately 1.6 to 1). Some analyses find the ratio in structures—most famously the Parthenon—built centuries before its first written formulation. More recently, scientists have found that the faces people find most beautiful are those in which the proportions conform most closely to the ratio.

The geometry-arithmetic connection explored by Taylor solves another puzzle that has enticed mathematicians across centuries. In 1637, French mathematician Pierre de Fermat scrawled in a book's margin a theorem involving equations like the one in the Pythagorean theorem ($a^2 + b^2 = c^2$), but with powers higher than two. Fermat's theorem said such equations have no solutions that are whole numbers, either positive *or* negative. Go ahead, try—it is impossible to find three integers, other than zero, that work in the equation $a^3 + b^3 = c^3$.

The French mathematician also wrote that he had discovered a way to prove this—but he never wrote the proof down, or if he did, it was lost. For more than 350 years, mathematicians tried in vain to prove what became known as Fermat's Last Theorem. They could find lots of examples that fit the pattern, and no counterexamples, but could not erase all doubt until Princeton University mathematician Andrew Wiles presented a proof in 1993.

His discovery made the front page of the *New York Times*, but six months later,



M.C. Escher's *Circle Limit III* illustrates the concept of hyperbolic space. Although the fish appear to get smaller toward the edge of the image, in the non-Euclidean world of hyperbolic geometry, the white lines along all the fishes' spines are actually the exact same length. Each fish is the same size as all the others, and an inhabitant of this world would have to walk an infinite distance to reach the circle's edge.