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EVOLUTION

What Made Us Unique

How we became a different kind of animal

By Kevin Laland | Scientific American September 2018 Issue

Credit: Victo Ngai

IN BRIEF

Human accomplishments derive from our ability to acquire knowledge from others and to use that communal store of experience to devise novel solutions to life's challenges.

Other species innovate, too. Chimps open nuts with stone hammers. Dolphins use a tool to flush out hidden prey.

Our uniqueness has to do with a capacity to teach skills to others over the generations with enough precision for building skyscrapers or going to the moon.

Most people on this planet blithely assume, largely without any valid scientific rationale, that humans are special creatures, distinct from other animals. Curiously, the scientists best qualified to evaluate this claim have often appeared reticent to acknowledge the uniqueness of *Homo sapiens*, perhaps for fear of reinforcing the idea of human exceptionalism put forward in religious doctrines. Yet hard scientific data have been amassed across fields ranging from ecology to cognitive psychology affirming that humans truly *are* a remarkable species.

The density of human populations far exceeds what would be typical for an animal of our size. We live across an extraordinary geographical range and control unprecedented flows of energy and matter: our global impact is beyond question. When one also considers our intelligence, powers of communication, capacity for knowledge acquisition and sharing—along with magnificent works of art, architecture and music we create—humans genuinely do stand out as a very different kind of animal. Our culture seems to separate us from the rest of nature, and yet that culture, too, must be a product of evolution.

The challenge of providing a satisfactory scientific explanation for the evolution of our species' cognitive abilities and their expression in our culture is what I call "Darwin's Unfinished Symphony." That is because Charles Darwin began the investigation of these topics some 150 years ago, but as he himself confessed, his understanding of how we evolved these attributes was in his own words "imperfect" and "fragmentary." Fortunately, other scientists have taken up the baton, and there is an increasing feeling among those of us who conduct research in this field that we are closing in on an answer.
The emerging consensus is that humanity's accomplishments derive from an ability to acquire knowledge and skills from other people. Individuals then build iteratively on that reservoir of pooled knowledge over long periods. This communal store of experience enables creation of ever more efficient and diverse solutions to life's challenges. It was not our large brains, intelligence or language that gave us culture but rather our culture that gave us large brains, intelligence and language. For our species and perhaps a small number of other species, too, culture transformed the evolutionary process.

The term “culture” implies fashion or haute cuisine, but boiled down to its scientific essence, culture comprises behavior patterns shared by members of a community that rely on socially transmitted information. Whether we consider automobile designs, popular music styles, scientific theories or the foraging of small-scale societies, all evolve through endless rounds of innovations that add incremental refinements to an initial baseline of knowledge. Perpetual, relentless copying and innovation—that is the secret of our species' success.

ANIMAL TALENTS

Comparing humans with other animals allows scientists to determine the ways in which we excel, the qualities we share with other species and when particular traits evolved. A first step to understanding how humans got to be so different, then, is to take this comparative perspective and investigate the social learning and innovation of other creatures, a search that leads ultimately to the subtle but critical differences that make us unique.

Many animals copy the behavior of other individuals and in this way learn about diet, feeding techniques, predator avoidance, or calls and songs. The distinctive tool-using traditions of different populations of chimpanzees throughout Africa is a famous example. In each community, youngsters learn the local behavior—be it cracking open nuts with a stone hammer or fishing for ants with a stick—by copying more experienced individuals. But social learning is not restricted to primates, large-brained animals or even vertebrates. Thousands of experimental studies have demonstrated copying of behavior in hundreds of species of mammals, birds, fishes and insects. Experiments even show that young female fruit flies select as mates males that older females have chosen.

FOLLOWING in the steps of others—social learning—has been a key to the success of *Homo sapiens* as long as it has existed as a separate species. Here members of the San group in Namibia walk the dunes single file. Credit: Kerstin Geier *Getty Images*

A diverse range of behaviors are learned socially. Dolphins possess traditions for foraging using sea sponges to flush out fish hiding on the ocean floor. Killer whales have seal-hunting traditions, including the practice of knocking seals off ice floes by charging toward them in unison and creating a giant wave. Even chickens acquire cannibalistic tendencies through social learning from other chickens. Most of the knowledge transmitted through animal populations concerns food—what to eat and where to find it—but there are also extraordinary social conventions. One troop of capuchin monkeys in Costa Rica has devised the bizarre habit of inserting fingers into the eye sockets or nostrils of other monkeys or hands into their mouths, sitting together in this manner for long periods and gently swaying—conventions that are thought to test the strength of social bonds.

Animals also “innovate.” When prompted to name an innovation, we might think of the invention of penicillin by Alexander Fleming or the construction of the World Wide Web by Tim Berners-Lee. The animal equivalents are no less fascinating. My favorite concerns a young chimpanzee called Mike, whom primatologist Jane Goodall observed devising a noisy dominance display that involved banging two empty kerosene cans together. This exhibition thoroughly

intimidated Mike's rivals and led to him shooting up the social rankings to become alpha male in record time. Then there is the invention by Japanese carrion crows of using cars to crack open nuts. Walnuts shells are too tough for crows to crack in their beaks, but they nonetheless feed on these nuts by placing them in the road for cars to run over, returning to retrieve their treats when the lights turn red. And a group of starlings—birds famously fond of shiny objects used as nest decorations—started raiding a coin machine at a car wash in Fredericksburg, Va., and made off with, quite literally, hundreds of dollars in quarters. [For further examples of how animals adjust to urban environments, see "Darwin in the City."]

Such stories are more than just enchanting snippets of natural history. Comparative analyses reveal intriguing patterns in the social learning and innovation exhibited by animals. The most significant of these discoveries finds that innovative species, as well as animals most reliant on copying, possess unusually large brains (both in absolute terms and relative to body size). The correlation between rates of innovation and brain size was initially observed in birds, but this research has since been replicated in primates. These findings support a hypothesis known as cultural drive, first proposed by University of California, Berkeley, biochemist Allan C. Wilson in the 1980s.

Wilson argued that the ability to solve problems or to copy the innovations of others would give individuals an edge in the struggle to survive. Assuming these abilities had some basis in neurobiology, they would generate natural selection favoring ever larger brains—a runaway process culminating in the huge organs that orchestrate humans' unbounded creativity and all-encompassing culture.

Initially scientists were skeptical of Wilson's argument. If fruit flies, with their tiny brains, could copy perfectly well, then why should selection for more and more copying generate the proportionately gigantic brains seen in primates? This conundrum endured for years, until an answer arose from an unexpected source.

COPYCATS

The Social Learning Strategies Tournament was a competition that my colleagues and I organized that was designed to work out the best way to learn in a complex, changing environment. We envisaged a hypothetical world in which individuals—or agents as they are called—could perform a large number of possible behaviors,

each with its own characteristic payoff that changed over time. The challenge was to work out which actions would give the best returns and to track how these changed. Individuals could either learn a new behavior or perform a previously learned one, and learning could occur through trial-and-error or through copying other individuals. Rather than trying to solve the puzzle ourselves, we described the problem and specified a set of rules, inviting anyone interested to have a go at solving it. All the entries—submitted as software code that specified how the agents should behave—competed against one another in a computer simulation, and the best performer won a €10,000 prize. The results were highly instructive. We found a strong positive relation between how well an entry performed and how well it required agents to learn socially. The winning entry did not require agents to learn often, but when they did, it was almost always through copying, which was always performed accurately and efficiently.

The tournament taught us how to interpret the positive relation between social learning and brain size observed in primates. The results suggested that natural selection does not favor more and more social learning but rather a tendency toward better and better social learning. Animals do not need a big brain to copy, but they do need a big brain to copy well.

This insight stimulated research into the empirical basis of the cultural drive hypothesis. It led to the expectation that natural selection ought to favor anatomical structures or functional capabilities in the primate brain that promote accurate, efficient copying. Examples might include better visual perception if that allows copying over greater distances or imitating fine-motor actions. In addition, selection should foster greater connections between perceptual and motor structures in the brain, helping individuals to translate the sight of others performing a skill into their producing a matching performance by moving their body in a corresponding way.

The same cultural drive hypothesis also predicted that selection for improved social learning should have influenced other aspects of social behavior and life history, including living in social groups and using tools. The reasoning was that the bigger the group and the more time spent in the company of others, the greater the opportunities for effective social learning. Through copying, monkeys and apes acquire diverse foraging skills ranging from extractive foraging methods such as digging grubs out of bark to sophisticated tool-using techniques such as fishing for termites with sticks. If social learning is what allows primates to pick up difficult-to-learn but productive food-procurement methods, any species proficient in

social learning should show elevated levels of extractive foraging and tool use. They should possess a richer diet and have longer lives, if that gives more time for learning new skills and passing them on to descendants. In sum, cultural drive predicts that rates of social learning will correlate not only with brain size but also with a host of measures related to cognitive performance.

Rigorous comparative analyses have borne out these predictions. Those primates that excel at social learning and innovation are the same species that have the most diverse diets, use tools and extractive foraging, and exhibit the most complex social behavior. In fact, statistical analyses suggest that these abilities vary in lockstep so tightly that one can align primates along a single dimension of general cognitive performance, which we call primate intelligence (loosely analogous to IQ in humans).

Chimpanzees and orangutans excel in all these performance measures and have high primate intelligence, whereas some nocturnal prosimians are poor at most of them and have a lower metric. The strong correlations between primate intelligence and both brain size measures and performance in laboratory tests of learning and cognition validate the use of the metric as a measure of intelligence. The interpretation also fits with neuroscientific analyses showing that the size of individual brain components can be accurately predicted with knowledge of overall brain size. Associated with the evolution of large primate brains are bigger and better-connected regions—neocortices and cerebellums—that allow executive control of actions and increased cortical projections to the motor neurons of the limbs, facilitating controlled and precise movements. This helps us to understand why big-brained animals show complex cognition and tool use. [For more on primate brains, see "Are We Wired Differently?"]
Plotting the intelligence measure on a primate family tree reveals evolution for higher intelligence taking place independently in four distinct primate groups: the capuchins, macaques, baboons and great apes—precisely those species renowned for their social learning and traditions. This finding is exactly the pattern expected if cultural processes really were driving the evolution of brain and cognition. Further analyses, using better data and cutting-edge statistical methods, reinforce these conclusions, as do models that make quantitative predictions for brain and body size based on estimates of the brain's metabolic costs.

Cultural drive is not the only cause of primate brain evolution: diet and sociality are also important because fruit-eating primates and those living in large, complex

groups possess large brains. It is difficult, however, to escape the conclusion that high intelligence and longer lives co-evolved in some primates because their cultural capabilities allowed them to exploit high-quality but difficult-to-access food resources, with the nutrients gleaned “paying” for brain growth. Brains are energetically costly organs, and social learning is paramount to animals gathering the resources necessary to grow and maintain a large brain efficiently.

NO CHIMP MOBILES

Why, then, don’t other primates have complex culture like us? Why haven’t chimpanzees sequenced genomes or built space rockets? Mathematical theory has provided some answers. The secret comes down to the fidelity of information transmission from one member of a species to another, the accuracy with which learned information passes between transmitter and receiver. The size of a species’ cultural repertoire and how long cultural traits persist in a population both increase exponentially with transmission fidelity. Above a certain threshold, culture begins to ratchet up in complexity and diversity. Without accurate transmission, cumulative culture is impossible. But once a given threshold is surpassed, even modest amounts of novel invention and refinement lead rapidly to massive cultural change. Humans are the only living species to have passed this threshold.

Our ancestors achieved high-fidelity transmission through teaching—behavior that functions to facilitate a pupil’s learning. Whereas copying is widespread in nature, teaching is rare, and yet teaching is universal in human societies once the many subtle forms this practice takes are recognized. Mathematical analyses reveal tough conditions that must be met for teaching to evolve, but they show that cumulative culture relaxes these conditions. The modeling implies that teaching and cumulative culture co-evolved in our ancestors, creating for the first time in the history of life on our planet a species whose members taught their relatives a broad range of skills, perhaps cemented through goal-oriented “deliberate” practice [see “Inside Our Heads.”]

CHIMPS AND HUMANS are both toolmakers. Chimpanzees use sticks to hunt for a meal of termites and pass this technique along to their kin. Unlike chimps, humans transmit cultural knowledge to offspring with a high degree of precision that enables the making of sophisticated technologies. Credit: Steve Bloom *Alamy* (*chimpanzees*); Chris Gunn *NASA* (*telescope mirror*)

The teaching of cultural knowledge by hominins (humans and their extinct close relatives) included foraging, food processing, learned calls, toolmaking, and so forth and provided the context in which language first appeared. Why our ancestors alone evolved language is one of the great unresolved questions. One possibility is that language developed to reduce the costs, increase the accuracy and expand the domains of teaching. Human language may be unique, at least among extant species, because only humans constructed a sufficiently diverse and dynamic cultural world that demanded talking about. This explanation has the advantage that it accounts for many of the characteristic properties of language, including its distinctiveness, its power of generalization and why it is learned [see "Talking through Time."]
Language began as just a handful of shared symbols. But once started, the use of protolanguage imposed selection on hominin brains for language-learning skills and on languages themselves to favor easy-to-learn structures. That our ancestors' cultural activities imposed selection on their bodies and minds—a process known as gene culture co-evolution—is now well supported. Theoretical, anthropological and genomic analyses all demonstrate how socially transmitted knowledge, including that expressed in the manufacture and use of tools, generated natural selection that transformed human anatomy and cognition. This evolutionary feedback shaped the emergence of the modern human mind, generating an evolved psychology that spurred a motivation to teach, speak, imitate, emulate, and share the goals and intentions of others. It also produced enhanced learning and computational abilities. These capabilities evolved with cumulative culture because they enhance the fidelity of information transmission.

Teaching and language were evolutionary game changers for our lineage. Large-scale cooperation arose in human societies because of our uniquely potent capacities for social learning and teaching, as theoretical and experimental data attest. Culture took human populations down novel evolutionary pathways, both by creating conditions that promoted established mechanisms for cooperation witnessed in other animals (such as helping those that reciprocate) and by generating novel cooperative mechanisms not seen elsewhere. Cultural group selection—practices that help a group cooperate and compete with other groups (forming an army or building an irrigation system)—spread as they proved their worth [see "The Origins of Morality."]

Culture provided our ancestors with food-procurement and survival tricks, and as each new invention arose, a given population was able to exploit its environment

more efficiently. This occurrence fueled not only brain expansion but population growth as well. Increases in both human numbers and societal complexity followed our domestication of plants and animals. Agriculture freed societies from the constraints that the peripatetic lives of hunter-gatherers imposed on population size and any inclinations to create new technologies. In the absence of this constraint, agricultural societies flourished, both because they outgrew hunter-gatherer communities through allowing an increase in the carrying capacity of a particular area for food production and because agriculture triggered a raft of associated innovations that dramatically changed human society. In the larger societies supported by increasing farming yields, beneficial innovations were more likely to spread and be retained. Agriculture precipitated a revolution not only by triggering the invention of related technologies—ploughs or irrigation technology, among others—but also by spawning entirely unanticipated initiatives, such as the wheel, city-states and religions.

The emerging picture of human cognitive evolution suggests that we are largely creatures of our own making. The distinctive features of humanity—our intelligence, creativity, language, as well as our ecological and demographic success—are either evolutionary adaptations to our ancestors' own cultural activities or direct consequences of those adaptations. For our species' evolution, cultural inheritance appears every bit as important as genetic inheritance.

We tend to think of evolution through natural selection as a process in which changes in the external environment, such as predators, climate or disease, trigger evolutionary refinements in an organism's traits. Yet the human mind did not evolve in this straightforward way. Rather our mental abilities arose through a convoluted, reciprocal process in which our ancestors constantly constructed niches (aspects of their physical and social environments) that fed back to impose selection on their bodies and minds, in endless cycles. Scientists can now comprehend the divergence of humans from other primates as reflecting the operation of a broad array of feedback mechanisms in the hominin lineage. Similar to a self-sustaining chemical reaction, a runaway process ensued that propelled human cognition and culture forward. Humanity's place in the evolutionary tree of life is beyond question. But our ability to think, learn, communicate and control our environment makes humanity genuinely different from all other animals.

A VISIT FROM E.T.

Imagine an extraterrestrial intelligence studying Earth's biosphere. Which of all the species would it identify as differing from the rest? The answer is humanity. Here are a few reasons:

Population size. Our numbers are out of kilter with global patterns for vertebrate populations. There are several orders of magnitude more humans than expected for a mammal of our size.

Ecological range. Our species distribution is extraordinary. Humans have colonized virtually every region of the terrestrial globe.

Environmental regulation. Humans control vast and diverse flows of energy and matter on unprecedented scales.

Global impact. Human activities threaten and are driving extinct unmatched numbers of species while eliciting strong evolutionary change across the biosphere.

Cognition, communication and intelligence. Experiments demonstrate superior performance by humans across diverse tests of learning and cognition. Human language is infinitely flexible, unlike the communication of other animals.

Knowledge acquisition and sharing. Humans acquire, share and store information on never-before-seen scales and build on their pooled cultural knowledge cumulatively from generation to generation.

Technology. Humans invent and mass-produce infinitely more complex and diverse artifacts than other animals.

The extraterrestrials might well be charmed by the elephant's trunk and impressed by the giraffe's neck, but it is humans that they would single out. —*K.L.*

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MORE TO EXPLORE

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FROM OUR ARCHIVES

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