TOPICS
TOPICS IN COGNITIVE SCIENCE

Topics in Cognitive Science 0 (2023) 1–25

ISSN: 1756-8765 online
DOI: 10.1111/tops.12656

This article is part of the topic "How Minds Work: The Collective in the Individual," Nat Rabb and Steven Sloman (Topic Editors).

What Makes Us Smart?

Joseph Henrich,[a] Michael Muthukrishna[b]

[a] *Department of Human Evolutionary Biology, Harvard University*
[b] *Department of Psychological and Behavioral Science, London School of Economics and Political Science*

Received 12 July 2022; received in revised form 4 April 2023; accepted 5 April 2023

Abstract

How did humans become clever enough to live in nearly every major ecosystem on earth, create vaccines against deadly plagues, explore the oceans depths, and routinely traverse the globe at 30,000 feet in aluminum tubes while nibbling on roasted almonds? Drawing on recent developments in our understanding of human evolution, we consider what makes us distinctively smarter than other animals. Contrary to conventional wisdom, human brilliance emerges not from our innate brainpower or raw computational capacities, but from the sharing of information in communities and networks over generations. We review how larger, more diverse, and more optimally interconnected networks of minds give rise to faster innovation and how the cognitive products of this cumulative cultural evolutionary process feedback to make us individually "smarter"—in the sense of being better at meeting the challenges and problems posed by our societies and socioecologies. Here, we consider not only how cultural evolution supplies us with "thinking tools" (like counting systems and fractions) but also how it has shaped our ontologies (e.g., do germs and witches exist?) and epistemologies, including our notions of what constitutes a "good reason" or "good evidence" (e.g., are dreams a source of evidence?). Building on this, we consider how cultural evolution has organized and distributed cultural knowledge and cognitive tasks among subpopulations, effectively shifting both thinking and production to the level of the community, population, or network, resulting in collective information processing and group decisions. Cultural evolution can turn mindless mobs into wise crowds by facilitating and constraining cognition through a wide variety of epistemic institutions—political, legal, and scientific.

Correspondence should be sent to Joseph Henrich, Department of Human Evolutionary Biology, Harvard University, 11 Divinity Ave, Cambridge, MA 02138, USA. E-mail: joseph.henrich@gmail.com

These institutions process information and aid better decision-making by suppressing or encouraging the use of different cultural epistemologies and ontologies.

Keywords: Cultural evolution; Innovation; Collective brain; Cultural epistomologies

---

Most researchers who have addressed the question of human creativity and intelligence are culturally WEIRD, meaning they grew up or were educated in societies that are Western, Educated, Industrialized, Rich and Democratic. Although people from diverse societies attribute technologies to ancient ancestors and both Chinese and American participants believe they have a better understanding merely because someone in their group knows more (Fullerton, Sloman, & Chan, 2020; Sloman & Rabb, 2016), not all societies focus so much on individual attributes, ascriptions, accomplishments, and mental life. For example, in some societies, speculation about mental states is taboo and moral culpability is a result of actions alone rather than both actions and mental states (Barrett et al., 2016; McNamara, Willard, Norenzayan, & Henrich, 2019), and in general, people in WEIRD societies make more dispositional attributions (Choi, Nisbett, & Norenzayan, 1999; Na & Kitayama, 2011). This WEIRD inclination toward individualism, dispositionalism, and analytic thinking (Henrich, 2020) leads many researchers to intuitively perceive individuals as autonomous and independent decision-makers endowed with properties or dispositions—abilities ("genius"), personalities ("hard worker"), attitudes, genes (for dispositions or abilities, such as IQ), and preferences—that account for their behavioral and psychological phenotypes. Further, unlike more holistic thinkers who focus on people's relationships, most cognitive scientists are potent analytic thinkers who tend to tackle problems—at least initially—by breaking complex systems down into their constituent parts and assigning them properties. If a person is creative, we break her thinking down into its cognitive and motivational processes to figure out how these may explain her creativity. If a society is innovative, the inclination is often to break the group down into individuals and assess the creativity of each member. This tendency may be strongest among those trained in psychology, which may be the WEIRDest scientific discipline (May, 1997).

This quest, to identify the "innovators," pervades both popular culture and scholarship, giving rise to what historians have dubbed "the myth of the heroic inventor" (Basalla, 1988; Mokyr, 1990)—an extension of Carlyle's "Great Man" theory of history. WEIRD people tend to see inventions as the creative products of geniuses who, through their own personal fortitude and solitary perspiration, take great leaps forward. Of course, as detailed studies make clear, new inventions, fresh insights, and novel ideas involve incremental steps that recombine—often through a healthy dose of serendipity—existing ideas, technologies, observations, and concepts (Ridley, 2020; Sneader, 2005; Williams, 1987). Typically, the key elements are already circulating within some community or social network, waiting for assembly. The near ubiquity of multiple invention—for example, calculus, radio, telephone, AC current, natural selection, and relative time—attests to the centrality of the social network and accumulation of circulating elements over the criticality of *singular* geniuses (Merton, 2013; Simonton, 1979).

Perpetuating this focus on the individual, both cognitive psychology and neuroscience suffer from what we might call the "myth of the heroic brain." This "Great Brain" theory of innovation implicitly or explicitly assumes that what makes us smart and creative are the innate algorithms or raw processing powers of individual brains. Consequently, different researchers variously argue over the secret of great brains—the powers of rationality, reasoning, mental models, frugal heuristics, and Bayesian computational abilities (Gershman, 2021; Gigerenzer & Goldstein, 1996; Gigerenzer, Todd, & Research Group, 1999; Herculano-Houzel, 2016; Mercier, 2017). By such accounts, we engineer powerful rocket engines, construct vast suspension bridges, craft stunning sculptures, design new vaccines, and compose sophisticated sonatas because "some person knuckles down, racks his brain, musters his ingenuity, and composes or writes or paints or invents something" (Pinker, 1997: 97), to quote one renowned cognitive scientist on how (he suspects) innovation happens.

Curiously, "Great Brain" theories of human innovation flourish despite well-established countervailing trends. Researchers in the psychological and economic sciences have long critiqued the assumption that decision-makers are rational, taking in and evaluating information on the costs and benefits of alternative options (Kahneman, 2011; Nisbett & Ross, 1980; Tversky & Kahneman, 1973)—though see Gershman (2021) on the Bayesian origins of such biases. A dive into this literature leaves one feeling hopeless. We humans (well, this research is done almost exclusively with WEIRD people, but that is a separate issue) appear to be complete morons: our reasoning is riddled with irrationalities, our perceptions are illusory, our judgments flawed in dozens of ways and when we do seek information, we take biased, small samples that mostly confirm our existing beliefs. Compounding these flaws, we suffer from a blindness to our own biases (Pronin, Lin, & Ross, 2002) and an illusion that we understand the world better than we do (Keil, 2003; Sloman & Fernbach, 2017). One might resolve this conflict by suggesting that the great geniuses represent those few who managed to escape these irrational biases, but the history of incredibly bad ideas supported by these exalted minds, not to mention the prevalence of multiple invention, suggests this is unlikely to resolve matters. So, how can we explain human creativity, technical innovation, and artistic flourishing, not to mention the immense ecological success of our species (Henrich, 2002)?

Here, taking a broader perspective, we deploy an evolutionary approach to humans as a cultural species that integrates a diverse body of research from different disciplines including those under rubrics, such as "the extended mind" (Clark & Chalmers, 1998), "collective intelligence" (Engel et al., 2015; Woolley, Chabris, Pentland, Hashmi, & Malone, 2010), "community-of-knowledge" (Sloman & Rabb, 2016), "cultural intelligence" (van Schaik & Burkart, 2011), and "distributed cognition" (Hollan, Hutchins, & Kirsh, 2000). Here, we explain how this collective brain evolved and how it shapes, sharpens, and distributes the cognitive abilities of each of its constituent brains. To do this, we draw on the Cultural Brain Hypothesis (Boyd, 2017; Henrich, 2016; Laland, 2017; Muthukrishna & Henrich, 2016; Muthukrishna, Doebeli, Chudek, & Henrich, 2018; Street, Navarrete, Reader, & Laland, 2017). Humans, to a degree not seen in other species, rely on a massive body of accumulated cultural information to survive and thrive, even in the harsh hunter–gatherer environments that characterized the last 2 million years of our evolutionary history. As evolved cultural learners, individuals adapt to their worlds not by figuring it out anew each generation, but by primarily learning from others, especially earlier generations. This information includes motivations, beliefs, skills, know-how, heuristics, (over)confidence, emotional reactions, decision heuristics, and attentional biases.

Computational modeling of the Cultural Brain Hypotheses (Muthukrishna et al., 2018) illustrates how brain size, life history, and the corpus of adaptive cultural knowledge can coevolve, driven by the autocatalytic interaction of genes and culture. As the cost of larger brains grew in terms of calorie requirements and challenges to birthing a big-brained baby, human life histories evolved to support an ever-growing cumulative cultural corpus. Gestation grew shorter, childhood extended, and menopause evolved, all driven by the selection pressures created by an ever-expanding body of adaptive cultural information capable of delivering fitness benefits to those capable of acquiring, storing, organizing, applying, and retransmitting this information (Kendal et al., 2018; Tomasello, 1999; Tomasello, Kruger, & Ratner, 1993). The resulting increase of 56 billion neurons over about 2 million years were "for"—from natural selection's perspective—learning from and transmitting to others, not for individually solving problems. These neural and life history changes were alone insufficient to store the ever-expanding body of knowledge, leading eventually to a division of information and labor (Migliano & Vinicius, 2022) and collective computation (Chater, 2022; Hollan et al., 2000; Hutchins, 1995). Crucially, our collective brains involve not just what we might normally think of as the elements of culture—tools, techniques, approaches, recipes, beliefs, and values—but also how we think and what we think about. That is, cultural evolution within collective brains rewrote our brains' software, giving us new ways of thinking, which ultimately made us cleverer (Dennett, 2009, 2017; Sterelny, 2012). Below, we highlight and summarize four insights that arise from the Cultural and Collective Brain Hypotheses:

1. Innovation and cumulative cultural evolution depend heavily on the size, interconnectedness, and diversity of a population's or network's collective brain.
2. Individual smartness, or the ability of individuals to solve locally relevant problems, depends on the products of cumulative cultural evolution and thus on the collective brain.
3. With the rise of distributed cognition and an informational division of labor as well as the challenge of increasingly diverse problems, cultural evolutionary incentives favor effective problem-solving in small groups and at scale. The problem-solving abilities of groups depend heavily on their cognitive diversity and social psychology as well as a wide range of interactional, organizational, and epistemological norms.
4. Collective decision-making—the ability of groups to make smart decisions—depends on culturally evolved norms that govern the interactions among individuals and subgroups as well as the selection of leaders.

This approach, with its focus on the selection pressures created by the interaction of cultural evolution and the environment, integrates a version of the Social Brain Hypothesis (Humphrey, 1976) with the Ecological Intelligence Hypothesis (Rosati, 2017). The approach considers different selection pressures than theories rooted in managing social relationships (Dunbar, 1993) and Machiavellian strategizing (Whiten & Byrne, 1997) as well as offering a distinctive set of predictions that partially overlap with these other hypotheses (Baimel, Juda, Birch, & Henrich, 2021).

Let us consider each of these insights.

1. Collective brains drive innovation

Based on a class of formal cultural evolutionary models (Creanza, Kolodny, & Feldman, 2017; Henrich, 2004; Kolodny, Creanza, & Feldman, 2015; Lehmann, Feldman, & Kaeuffer, 2010; Mesoudi, 2011; Powell, Shennan, & Thomas, 2009), the ability of communities—or collective brains—to innovate depends on: (1) the size of the community of potential innovators; (2) their social interconnectedness or subpopulation structure; (3) cultural transmission technologies and tendencies; and (4) their cognitive diversity. Below, we sketch each prediction and the current evidence.

First, both population size and the social interconnectedness of individuals should have a substantial influence on the rate of innovation and the steady-state level of cultural complexity, which includes technical know-how, linguistic repertoires, recipes, and other aspects of culture. *Ceteris paribus*, populations with more individuals are both more likely to generate new ideas, whether through serendipity, insight, or some combination, and better able to resist the chance loss of rare domains of know-how, experience, expertise, or arcane forms of cultural knowledge (which may be, or become, important). Such losses may remove not only useful or clearly recognized know-how from a population, but can also involve the disappearance of seemingly unproductive elements that nevertheless reduce the population's ability to adapt to future conditions by, for example, providing an essential ingredient for a future recombinant innovation. Crucially, from the point of view of the individual, the *same person* will appear more creative when they live in a larger population or network. Broadly, a large body of both observational and experimental evidence supports the power of population size.

Unlike population size, where generally bigger is better, there is an optimal level of social interconnectedness that maximizes both the rate of innovation and the steady-state level of cultural complexity (Campbell, Izquierdo, & Goldstone, 2022; Derex, Perreault, & Boyd, 2018; Derex & Boyd, 2016; Schimmelpfennig, Razek, Schnell, & Muthukrishna, 2022). In most historical contexts, greater interconnectedness has favored faster cumulative cultural evolution and higher levels of stable cultural complexity. Greater connectivity among diverse minds in these situations creates more opportunities for ideas to interact and generate novel recombinations (Creanza et al., 2017; Kolodny et al., 2015; Lewis & Laland, 2012). Because the nature of cultural evolution and cooperation means that growing populations tend to fragment and fractionate (Henrich, 2016), the challenge that has confronted most societies and organizations has been staying socially connected and cooperative.

Nevertheless, both theoretical and experimental research suggest that too much interconnection can reduce the rate of cumulative cultural evolution, thus slowing innovation (Derex et al., 2018; Derex & Boyd, 2016; Migliano et al., 2020; Schimmelpfennig et al., 2022). This arises for a couple of interrelated reasons. First, many problems have multiple solutions, each of which can only be obtained by following a different cultural evolutionary pathway involving gradual, cumulative innovations or modifications. Once perfected, or at least substantially improved, these different approaches may vary in their effectiveness and overall desirability. Second, if populations are not too interconnected, different solutions may emerge and undergo at least some independent development and improvement. This "let a thousand flowers bloom" approach allows multiple solutions to compete on a more equal footing, which increases the chances that the best long-run solution will be found. However, if a population is too interconnected, an inferior solution may spread widely very quickly and undergo rapid improvement. Even if someone discovers an alternative pathway that may eventually lead to a superior solution, the early versions of most efforts will often be inferior to the much-improved version of the first pathway explored. Thus, populations that are too interconnected can get stuck on suboptimal solutions. The electric car, for example, was invented in the 19th century and represented over one-third of cars manufactured in the United States in 1900 (Martin, n.d.; Standage, 2021). But, in 1908, Henry Ford delivered the Model T, which crushed the competition on both price and range (before refueling). As a result, electric cars largely vanished from American roads for a century, Americans went up a suboptimal and ultimately dangerous peak—as recent developments in electric cars illustrate. Beyond the impact of multiple solutions, too much interconnectedness may reduce a population's overall cultural diversity, which reduces the ambient levels of variation that provide ingredients for novel recombinations. As with population size, the creativity or innovativeness of individuals depends on the social network or community they reside within.

Technologies and institutions that evolved for cultural transmission, such as schools (Ritchie & Tucker-Drob, 2018), Sesame Street (Kearney & Levine, 2019), and perhaps the Internet/social media (Parise, Whelan, & Todd, 2015), are all ways of potentially transmitting some ideas more effectively and particular types of cognitive skills, ranging from reading, writing, and arithmetic to self-regulation, temporal discounting, and argumentation. Formal education in particular is an efficient tool for transmitting a culturally evolved corpus to young humans, preparing them to take part in and succeed in the adult worlds of their societies (Ritchie & Tucker-Drob, 2018).

Finally, because most innovations are recombinations (Thagard, 1998; Youn, Strumsky, Bettencourt, & Lobo, 2015), a population's cognitive diversity supplies crucial fuel for the fires of creativity. Here, cognitive diversity includes domains of knowledge and expertise as well as ways of thinking, feeling, and perceiving—that is, information processing. Cognitive differences arise from many sources, including languages, cultural backgrounds, personal experiences, formal training, and genetic endowments. Differences in sound perception, for example, are influenced by both musical training and fluency in a tonal language like Mandarin or Zapotec (Blasi, Henrich, Adamou, Kemmerer, & Majid, 2022). Social interactions among cognitively diverse individuals increase the chances of novel recombinations and serendipitous insights (Page, Cantor, & Phillips, 2019).

A large body of ethnohistorical, experimental, and observational evidence supports the predictions derived from the collective brain. For example, by combining U.S. patent data with Census data from 1880 to 1940, Winkler et al. (n.d.) show not only that more populous counties produce more innovations per capita but that this effect further increases in more cognitively diverse counties. Here, the results hold whether "innovations" are measured using (1) simply patents per capita or (3) breakthrough patents per capita derived by analyzing the introduction of novel concepts. As a proxy for cognitive diversity, the authors used surnames, showing how they capture variation in cultural background, family traditions, and occupational differences, among other elements of diversity. To confirm that the effects are driven by diversity, the authors compare people with the same surname who live in counties with varying levels of diversity. The results show that bearers of the same surname are more innovative—produce more patents—when they live in more diverse counties.

To go beyond these correlational results, Winkler and colleagues also identify quasi-experimental random variation by looking at the effects of immigration. For idiosyncratic reasons, such as famines in Eurasia and the laying of railroad tracks near some American towns (but not others), immigrants are more likely to arrive in some U.S. counties over others in ways that vary over time. The results reveal that immigration drives innovation by increasing a county's cognitive (surname) diversity. Notably, larger inflows of immigrants increase the patenting activity of native-born individuals in these counties, making them more creative. These results confirm, and inform, a growing body of evidence showing how immigration has propelled innovation over U.S. history and that this has consistently increased the innovativeness of native-born Americans (Akcigit, Grigsby, & Nicholas, 2017; Burchardi et al., 2021; Nunn, Qian, & Sequeira, 2017; Sequeira, Nunn, & Qian, 2020).

The powerful effects of immigration on innovation were starkly observed with the enactment of the Johnson–Reed Act (1924), which limited immigration from Eastern and Southern Europe (Moser & San, 2020). After 1924, patenting dropped by two-thirds across the 36 fields in which Eastern Europeans had made contributions prior to 1924—fields like radiation, radio, and polymers. Without this influx of new ideas, native-born Americans became less creative, experiencing a 62% decline in patenting. A decade after President Johnson had ended these quotas in 1964, U.S. innovation was again fueled by immigrants coming from Mexico, China, Vietnam, and the Philippines (Burchardi, Chaney, & Hassan, 2019).

The collective brain makes sense of another well-established pattern: larger U.S. cities and more interconnected counties—via transportation infrastructure—produce disproportionately more innovations per capita (Bettencourt, Lobo, & Strumsky, 2007, 2010). The rate of patenting per person in U.S. counties doubles in the two decades after the arrival of train lines, wiring these counties into America's collective brain (Perlman, n.d.).

Under more controlled laboratory conditions, the role of population size and interconnectedness has now been tested in several laboratory experiments where researchers have explored and compared the role of specific mechanisms. These experiments often exploit in-lab cultural transmission chains. In one battery of experiments, researchers kept population size constant but adjusted interconnectivity. Participants in the treatment condition with access to more "teachers" from the previous generation maintained higher skill levels in a series of rock-climbing knots and better learned to use the Gimp photo-editing tool to replicate a complex target image. Both the more-connected and less-connected treatments had their naturally gifted knot-tiers and photo editors, but only those in the connected condition could improve upon the previous generation's best efforts. Further analyses of the transmission patterns of specific elements in the task revealed that interconnected participants were strategically learning from the best performers in the previous generation, recombining different elements they got correct or were more adept at teaching. In the final generation, the worst-performing participant in the more-connected condition was better than the best-performing participant in the less-connected condition (Muthukrishna, Shulman, Vasilescu, & Henrich, 2014)—illustrating how the collective brain dominates any differences among individual brains. Complementary experiments show that larger groups similarly result in more innovation and greater cultural accumulation (Derex, Beugin, Godelle, & Raymond, 2013; Kempe & Mesoudi, 2014) and that partially connected populations structured into subgroups can outperform fully connected groups (Derex & Boyd, 2016). Taken together, these experiments illustrate how the collective brain dominates any differences among individual brains. After only 10 laboratory generations, all individuals from groups with larger collective brains can outperform every individual from groups with smaller collective brains.

The evidence presented above reveals how living in larger, more diverse, and optimally interconnected populations can make individuals more creative and innovative. But can the collective brain and cumulative cultural evolution make them better at problem-solving independent of these social or network factors?

2. Collective brains make us individually smarter

Faster cumulative cultural evolution, fueled by larger collective brains, can make individuals smarter in the sense of being better able to tackle the *novel* problems posed by their societies and environments. This occurs in several different ways, many of which have not been studied in detail.

Perhaps the clearest and most obvious way is by supplying individuals with concrete cultural products that embody or distill both specific solutions and general concepts that can be redeployed and recombined to produce innovations. Over the course of human history, for example, technologies involving wheels, pulleys, levers, wedges, and screws have evolved culturally and spread. Each of these was initially hard to invent (rarely thought of), but once invented, both the application and the underlying concept became easier to learn (from a working exemplar) and redeployed in novel ways. The wheel, for example, appears to have only been invented once in human history, and only in Eurasia. Initially, wheels were used for carts and pottery, but later, the concept was applied to mills, clocks, and industrial machines (Henrich, 2016).

Beyond concepts that can be embedded in physical technologies like screws, cumulative culture and collective brains have also generated mathematical tools and concepts, beginning with numbers themselves. Societies vary from lacking discrete integers (neither words nor sharp concepts) to possessing systems that permit them to count without bound. Many societies, for example, traditionally counted "1, 2, 3, many," lacking any discrete integers above 3. Others used body parts systems to variously count to 10, 12, 17, and 28. Comparative psychological research suggests that the habitual use of particular practices or customs can foster the development of novel numerical abilities that distinguish humans from other animals (Bender & Beller, 2012; Gordon, 2005; Overmann, 2015; Pica, Lerner, Izard, & Dehaene, 2004).

As societies scaled up, some added written representations of numbers, which variously took advantage of different bases (2, 10, 12), place values (the "2" in "21" represents 20), and a number symbol for nothing ("0"). Today, essentially all societies have adopted Hindu-Arabic numbers, which largely developed in India, spread to Persia, entered the Islamic world, and finally penetrated Europe, where elites resisted both "Arabic" numbers and the zero symbol (Seife, 2000; Starr, 2015).

Numeracy, like literacy, is a culturally evolved cognitive upgrade that gives us new mental capacities. Cumulative cultural evolution operating over thousands of years has gradually produced a growing list of concepts and techniques for dealing with actual and symbolic quantities, including addition, subtraction, division, multiplication, fractions, decimals, powers, equations, algebra, logarithms, geometry, probabilities, and many more (Bose, 2018). These cognitive tools allow even elementary school children to readily conceptualize and solve all manner of problems that would have seemed impossible to the smartest people in earlier societies.

Cumulative cultural evolution has also shaped our perception (Yoon et al., 2014). Consider color: while some small-scale societies have 0 or 2 abstract (basic) color terms, like extensive versions of "black" and "white," many larger-scale societies have over 10 such basic color terms. Recent evidence suggests that speakers of languages with labels that distinguish color terms can more easily highlight fine-grained distinctions. Not surprisingly, people are better at distinguishing shades that are labeled with different terms in their language, but worse at distinguishing shaped groups under the same label (Allred & Flombaum, 2014; Deutscher, 2011). Russians, for example, have different words for lighter blues ("goluboy") and darker blues ("siniy"). English has no such distinction. Russian speakers were faster at discriminating these two colors compared to English speakers with larger effects where the colors presented were perceptually closer (Winawer et al., 2007). Exploiting a parallel terminological distinction in Greek using event-related potentials (ERPs), Thierry, Athanasopoulos, Wiggett, Dering, and Kuipers (2009) show distinct automatic, preattentive neurological responses to linguistically marked shades of blue (but not unmarked shades of green) in Greek speakers but not English speakers. The results indicate that the brains of Greek speakers reacted automatically in a nonlinguistic task to pattern deviations marked in their language, while English speakers did not.

Unlike in our industrialized world where control over pigments can offer identical shirts in a spectrum of colors, in foraging societies, color rarely uniquely marks crucial distinctions. Olfaction, however, plays a larger and more important role. Recent work among foraging populations in Bolivia and Malaysia reveals that these populations possess both richer vocabularies for describing scents, deploying a large number of basic olfactory terms, and are superior at identifying odors (Majid & Kruspe, 2018; Sorokowska, Sorokowski, Hummel, & Huanca, 2013).

These patterns are consistent with evolutionary approaches arguing that our brains have evolved genetically to adapt ontogenetically to hone our cognitive abilities, responding to the social, technological, and institutional incentives and prestige hierarchies of our societies (Henrich, 2016; Heyes, 2018). To prepare individuals, cumulative cultural evolution has shaped children's games, schooling institutions, and the routines of daily life in ways that cultivate the cognitive skills that promote success in particular societies. For example, in many small-scale societies, foraging forays away from the community foster the development of skills in spatial navigation that permit children to safely travel through forests, woodlands, and deserts. The development of these abilities is often reduced or inhibited when children attend formal schools (Cashdan, Kramer, Davis, Padilla, & Greaves, 2016; Davis et al., in press; Davis & Cashdan, 2019). The variation in school curricula, quality, and schooling cultures between and within countries reveals the rich and diverse ways that modern schooling shapes our cognitive and motivational capacities with consequent effects on several cognitive abilities (Ripley, 2013).

Building on existing work (Flynn, 2007), we have argued that in many modern societies, a variety of cultural factors have cultivated a set of specialized cognitive skills that foster success in the meritocratic institutions of these societies (Flynn, 2012; Furnham & Cheng, 2013; Muthukrishna & Henrich, 2016; Nisbett et al., 2012). These cognitive skills, which have improved dramatically over the last century in the wealthiest societies, relate primarily to analytic thinking, including abstract problem-solving, working memory, and pattern recognition. Indeed, some of the most striking increases have occurred in the supposedly "culture free" aspects of cognition, such as those measured by Raven's Matrices and the three analytic subtests of the Weschler IQ battery. In the particular societies commonly studied by psychologists, measures of these cognitive abilities tend to cluster, giving researchers the impression that they form some innate dimension of "intelligence." Of course, what a particular society labels "intelligence" may represent merely the suite of cognitive skills that promote success or prestige within that society during a particular era. Consistent with this, Uchiyama, Spicer, and Muthukrishna (2022) argue that the genetic heritability of any traits favored by cultural evolution in a particular ecological or institutional environment, such as the cognitive suite labeled "IQ," will tend to increase over time—cultural evolution can operate to decrease the total phenotypic variance or increase a trait's genetic variance (Zeng & Henrich, 2022).

Consistent with this view, studies of schooled and unschooled populations show that the "natural" maturational patterning of IQ arises from the interaction between maturation and schooling (Davis, 2014). Indeed, meta-analyses of causal and quasi-experimental studies suggest that "Education appears to be the most consistent, robust, and durable method yet to be identified for raising intelligence" (Ritchie & Tucker-Drob, 2018). Since universal schooling is relatively recent, and did not exist at all over most of human evolutionary history, much of the work on "intelligence" and IQ is really a form of cultural psychology.

For our current purposes, the point is that cumulative cultural evolution has fostered a suite of cognitive skills that made people "smarter" in the sense of being better able to meet the cognitive challenges posed by their societies and environments. Consistent with this, Greenfield (1998) points out that early in the 20th century, IQ scores in rural American towns increased dramatically just as these towns were wired into the United States' collective brain through investment in schools, roads, and railroads. The same process can be observed a half-century later in Guatemala and a full century later among the Tsimane in the Bolivian Amazon. Growing Collective Brains made people "smarter" in the culturally situated sense captured by IQ tests.

Finally, cumulative cultural evolution has shaped a variety of cultural ontologies and epistemologies. The ontologies and epistemologies that we acquire as a consequence of growing up in a particular place influence the kinds of explanations we consider, the types of evidence we value, and our assessments of what constitutes a good argument. We culturally inherit fundamental ontologies about how the world works. For example, if you are feeling sick, which of the following do you consider as a potential cause: (1) germs, (2) envy from others, (3) sorcery, or (4) genes? Even if you are not sure, the candidate cause can impact your actions and thus the kinds of innovations you might devise. In many, if not most, populations over human history, witchcraft was considered a major cause of illness (Singh, 2021). In many societies, both today and historically (Gershman, 2022), when a person dies unexpectedly, inquests and trials are conducted, evidence is presented, arguments are made, verdicts are rendered, and executions of witches are carried out. In England, for example, witchcraft trials did not completely disappear until 1944, when Helen Duncan was convicted under the Witchcraft Act of 1735 for revealing military secrets that she had (purportedly) obtained during seances. Without reviewing the evidence, which convinced a jury, those of us with a WEIRD ontology feel confident that she was wrongly convicted. But have you reviewed the evidence against witchcraft? Probably not. Despite the intuitive attractiveness of witchcraft-based explanations, your skepticism arises not from your evaluation of evidence, but from the collective brain operating through a cumulative cultural evolution to gradually filter out ineffective ontologies and epistemologies. Your skepticism of witchcraft-based explanations was bequeathed to you by your cultural ancestors.

Similarly, dreams have been considered a valuable form of evidence across many populations, including philosophically sophisticated societies like ancient Greece and China (Hong, 2021). Among both emperors and peasants, dream evidence has been used to make life and death decisions about battles, illnesses, disasters, and pregnancies. In China, specialists in dream interpretation assisted emperors for over 2000 years to make important state decisions. Official reports from the period would appear to confirm the accuracy of dreams. Today, those exposed to WEIRD ontologies generally do not use their dreams as evidence about what is likely to occur in the future (though of course, there is a fringe industry). This too is not because they have reviewed the corpora of evidence against the epistemological value of dreams. Instead, cumulative cultural evolution gradually reduced the consideration of dreams as evidence.

Cultural evolution, operating via the collective brain, alters our ontologies and epistemologies outside of conscious awareness, gradually shaping them to aid us both individually and collectively in making better decisions and employing practices more likely to work.

3. The informational division of labor and collective intelligence

The Cultural Brain Hypothesis argues that the rapid expansion of our brains was driven by the ever-increasing body of adaptive information, including heuristics, know-how, practices, attentional biases, and much more, made available by cultural evolution to learners with sufficient capacities for acquiring, storing, and organizing this information (Henrich, 2016;

Muthukrishna et al., 2018). However, based on estimates from fossils, our species cranial expansion likely stabilized roughly 200,000 years ago or more. Debates persist, but the leading hypothesis for why our brains stopped enlarging relates to the rising costs of birthing "big-headed" babies and the phylogenetic constraints imposed by the female body plan (Boyd & Silk, 2014). Even today, bigger heads result in more emergency cesarean sections and instrumental interventions (Lipschuetz et al., 2015). Nevertheless, opportunities to take advantage of the adaptive information created by cumulative cultural evolution persisted.

One way to further exploit the available cultural information would have been to subdivide communities into specialists such that cultural know-how was distributed across the minds of community members (Ben-Oren et al., 2022). Likely the first and most enduring partition of cultural know-how and skills occurred between males and females (Hooper, Demps, Gurven, Gerkey, & Kaplan, 2015; Schniter, Gurven, Kaplan, Wilcox, & Hooper, 2015, 2018), with women often focusing on developing expertise in activities surrounding infant care and productive activities that could be done with young children in tow. Beyond the sexual division of labor, particular community members may have specialized in various ways (Hooper et al., 2015), including in medicinal plant use, shamanism, and the manufacture of skill-intensive crafts, such as making fires, arrows, and skin boats. An intergroup exchange may have permitted different communities to specialize in certain skills leading to the beginnings of commerce (Henrich & Boyd, 2008; Migliano & Vinicius, 2022).

The emergence of a community-level cognitive division of labor may be sufficiently old that it has influenced our species' genetic evolution. Cognitively, such evolutionary processes may explain both why individuals readily think of themselves as part of a collective brain, with distributed knowledge, and readily assume the existence of specialists to facilitate learning and information seeking. For example, young children in WEIRD societies, and probably others, readily understand that different specialists have different information and can readily learn the role of disciplinary expertise for the purposes of knowledge seeking (Keil, Stein, Webb, Billings, & Rozenblit, 2008; Lutz & Keil, 2002). At the same time, in the "community of knowledge" phenomenon, adults in both the United States and China fail to distinguish between what they personally know and what is understood by someone in their group (Fullerton et al., 2020; Sloman & Rabb, 2016)—they implicitly recognize they are part of a collective brain. In addition, the rise of a division of labor may have reduced the selection pressures sustaining our large, costly brains, leading to the decline in brain size observed in humans over the last 20,000 years (DeSilva, Traniello, Claxton, & Fannin, 2021), though the simulations of the Cultural Brain offer other explanations as well.

In the modern world, the innovative potential of countries depends on the distribution of know-how: the occupational or productive specializations of cities or countries predict the new industries or products that can be developed. Hidalgo, Hausman, and colleagues (2009; 2007; 2011), for example, show that countries cannot innovate in a certain industry or product type unless they already have particular other related product types or industries in place. These authors argue that this arises from the role of tacit knowledge—the skill or know-how necessary to accomplish specific productive activities that cannot be conveyed in an instruction manual or taught in school, but only learned through apprenticeship, hands-on training, and interactions with experts.

Like other animals, including ants, bees, and birds (DeSilva et al., 2021; Morand-Ferron & Quinn, 2011; Pike & Laland, 2010; Sasaki, Granovskiy, Mann, Sumpter, & Pratt, 2013; Seeley, 2010), humans can also take advantage of methods for aggregating information in ways that sharpen their observations, judgments, and decisions. However, unlike nonhumans, we have culturally evolved institutions for aggregating information that influence the ability of groups or communities to make smart decisions that depend not only on the cognitive abilities of the individuals involved but also on their diversity and norms of social interaction.

Focusing on decision-making and problem-solving in small groups or teams (Engel et al., 2015; Page et al., 2019; Riedl, Kim, Gupta, Malone, & Woolley, 2021; Woolley et al., 2010, 2015), psychologists and cultural evolutionists have explored the factors that contribute to "smarter" groups. These findings confirm the basic logic of collective brain dynamics. Groups composed of more intelligent individuals, based on IQ, tend to have greater "collective intelligence," though the relationship is relatively moderate (Engel, Woolley, Jing, Chabris, & Malone, 2014; Woolley et al., 2010, 2015). Crucially, members of smarter groups are more willing and able to take each other's perspectives and listen without interrupting (Engel et al., 2014; Meslec, Aggarwal, & Curseu, 2016), and introducing individuals with social skills for collaboration has as large an effect on team performance as individual IQs (Weidmann & Deming, 2021). In a social network, when individuals are permitted to break social ties and reform new ones, they form networks that are even better at the collective judgment (Almaatouq et al., 2020). Finally, although greater cognitive diversity often increases a group's problem-solving abilities (Page et al., 2019), the cases in which diversity fails to predict improved problem-solving seem to confirm the theory—they involve cases in which measured "diversity" was not associated with relevant informational/cognitive diversity or in which diversity resulted in less social interconnectedness, shrinking the collective brain (Schimmelpfennig et al., 2022; Sulik, Bahrami, & Deroy, 2022).

4. Epistemic institutions

The psychological literature on collective intelligence and team innovation strongly suggests that social norms impact people's creativity and innovation by shaping organizations and influencing social interactions. These organizational traits can evolve culturally under the influence of intergroup competition: institutions that generate faster innovation or more reliable knowledge can spread in a variety of ways. The most obvious norms, institutions, or policies that might influence intergroup competition flow directly from the standard findings in the collective intelligence literature: organizational norms and policies can influence (1) cognitive diversity and perspective taking through the recruiting and assignment of new members, (2) the ability of members to interact socially and vicariously (including opportunities for people to form their own networks), (3) people's openness and receptivity to novel ideas and fresh questions or claims, both of which are shaped by the cultivation of interpersonal harmony, an egalitarian ethos and the suppression of dominance-oriented status-seeking (e.g., bullying, etc.).

However, beyond these elements, organizations and communities today and over historical time have possessed quite different ontological and epistemic norms. As noted, different notions of what exists (e.g., witches) or what constitutes a good argument or reliable evidence have evolved culturally. Some organizations today, such as religious communities, find arguments that invoke supernatural agents and sacred scriptural references as perfectly acceptable. That does not mean that they immediately believe such arguments and evidence, but such arguments do not fall out of bounds. For example, the brilliant 13th-century theologian, Thomas Aquinas, unapologetically explored topics such as whether angels were corporal or incorporeal and in turn, whether several angels could be in the same place at the same time. This in turn led to later concerns about angels crowding together on the heads of pins. Obviously, scientific institutions today impose rather different ontological and epistemological standards. Echoing Aquinas, a young physicist today may explore quantum superpositions or reconciling quantum mechanics with general relativity, but they would not posit a supernatural agent to resolve the puzzle nor draw as evidence some combination of their own lucid dreams and textual evidence from Confucius, Mayan texts, and the Gospel of John. She could, as Laplace and Newton did with gravitons and photons, posit a particle with particular properties. Ontologically, making up new particles is fine, just not new (or old) supernatural agents. Of course, banishing the influence of the ancient sages and sacred scripture lies at the center of scientific epistemology—no appeals to authority in making your case. Newton himself was criticized by the Cartesians for positing a "mystical" gravitational force that could instantaneously act over great distances without any physical connections or contacts. The Cartesians happened to be right about gravity, which propagates at the speed of light not instantaneously, but their reasoning was flawed by modern scientific standards—a "mystical" instantaneous connection between entangled particles is "spooky" but ultimately acceptable. The rules by which we decide what is true and evaluate evidence are culturally acquired without direct experience nor direct evaluation of that evidence, which in any case, would be evaluated and debated based on culturally acquired standards.

The norms of an organization can institutionalize debate as we see in legislative assemblies, legal proceedings, scientific journals, and conferences (Goodin, 2017). Debating formats, where each side must defend their position, may take advantage of certain psychological mechanisms that make us good at spotting the evidentiary and logical flaws in other people's arguments but not so good at identifying the shortcoming of the arguments we devise to defend our own beliefs (Mercier, 2016; Mercier & Sperber, 2011). Of course, people can be trained to improve their arguments, but part of that training is learning how to see your arguments from the vantage of others (Castelain, Girotto, Jamet, & Mercier, 2016). Policies and laws surrounding free speech and academic freedom further enhance and safeguard the potential for generating reliable knowledge (Rauch, 2021). Interestingly, as with many of the practices that improve group-level innovation and creativity, individuals are bad at recognizing these norms and designing effective institutions (Mercier, Trouche, Yama, Heintz, & Girotto, 2015): for example, both experts and others underestimate the power of argumentation. Moreover, the way in which these norms are shifting through new communities created by the Internet and online social networks is still evolving and yet to be worked out.

Other institutions have gradually developed other epistemic-enhancing norms, practices, or laws. Some legal bodies, including both the Canadian Supreme Court and the Great Sanhedrin (the ancient assembly in Israel), had the lowest-ranking members offer their views first, before they were tainted by hearing those of more senior members (Henrich, 2016). Similarly, the secret ballot spread only slowly to other modern democracies after France included it in their new constitution (1795). Today, most countries use the "Australian ballot," after it began in Tasmania in 1856. This institution surrounds the secret ballot concept with a set of practical requirements that help guarantee secrecy. Curiously, while the Australian ballot is now nearly universal, some U.S. states like West Virginia have still not adopted it.

In conclusion, a growing body of evidence supports the view that, propelled by our species' capacities for learning from each other—our cultural capacities—humans have evolved to be ultra-social, deeply dependent on a large body of cumulative cultural knowledge for our very survival, and adapted to thinking, remembering, and reasoning as a collective (Boyd, 2017; Henrich, 2016; Muthukrishna & Henrich, 2016; Rabb, Fernbach, & Sloman, 2019). Human cognition can, therefore, only be understood when seated within its social, historical, and evolutionary context (Muthukrishna, Henrich, & Slingerland, 2021).

References

Akcigit, U., Grigsby, J., & Nicholas, T. (2017). Immigration and the rise of American ingenuity. *American Economic Review*, *107*(5), 327–331.

Allred, S. R., & Flombaum, J. I. (2014). Relating color working memory and color perception. *Trends in Cognitive Sciences*, *18*(11), 562–565.

Almaatouq, A., Noriega-Campero, A., Alotaibi, A., Krafft, P. M., Moussaid, M., & Pentland, A. (2020). Adaptive social networks promote the wisdom of crowds. *Proceedings of the National Academy of Sciences*, *117*(21), 11379–11386.

Baimel, A., Juda, M., Birch, S., & Henrich, J. (2021). Machiavellian strategist or cultural learner? Mentalizing and learning over development in a resource-sharing game. *Evolutionary Human Sciences*, *3*, e14.

Barrett, H. C., Bolyanatz, A., Crittenden, A. N., Fessler, D. M., Fitzpatrick, S., Gurven, M., Henrich, J., Kanovsky, M., Kushnick, G., & Pisor, A. (2016). Small-scale societies exhibit fundamental variation in the role of intentions in moral judgment. *Proceedings of the National Academy of Sciences*, *113*(17), 4688–4693.

Basalla, G. (1988). *The evolution of technology*. Cambridge University Press.

Bender, A., & Beller, S. (2012). Nature and culture of finger counting: Diversity and representational effects of an embodied cognitive tool. *Cognition*, *124*(2), 156–182.

Ben-Oren, Y., Kolodny, O., & Creanza, N. (2023). Cultural specialization as a double-edged sword: Division into specialized guilds might promote cultural complexity at the cost of higher susceptibility to cultural loss. *Evolutionary Biology*. https://doi.org/10.1101/2022.04.22.489202

Bettencourt, L. M. A., Lobo, J., & Strumsky, D. (2007). Invention in the city: Increasing returns to patenting as a scaling function of metropolitan size. *Research Policy*, *36*(1), 107–120.

Bettencourt, L. M. A., Lobo, J., Strumsky, D., & West, G. B. (2010). Urban scaling and its deviations: Revealing the structure of wealth, innovation and crime across cities. *PLoS ONE*, *5*(11), 20–22.

Blasi, D. E., Henrich, J., Adamou, E., Kemmerer, D., & Majid, A. (2022). Over-reliance on English hinders cognitive science. *Trends in Cognitive Sciences*, *26*(12), 1153–1170.

Bose, S. K. (2018). Evolution of mathematics: A brief sketch. *Open Access Journal of Mathematical and Theoretical Physics*, *1*(6), 249–254.

Boyd, R. (2017). *A different kind of animal: How culture transformed our species*. Princeton University Press.

Boyd, R., & Silk, J. B. (2014). *How humans evolved*. W.W. Norton & Company.

Burchardi, K. B., Chaney, T., & Hassan, T. A. (2019). Migrants, ancestors, and foreign investments. *Review of Economic Studies*, *86*(4), 1448–1486.

Burchardi, K. B., Chaney, T., Hassan, T. A., Tarquinio, L., & Terry, S. J. (2021). *Immigration, innovation, and growth*.

Campbell, C. M., Izquierdo, E. J., & Goldstone, R. L. (2022). Partial copying and the role of diversity in social learning performance. *Collective Intelligence*, *1*(1). https://doi.org/10.1177/26339137221081849 1-15

Cashdan, E., Kramer, K. L., Davis, H. E., Padilla, L., & Greaves, R. D. (2016). Mobility and navigation among the Yucatec Maya. *Human Nature*, *27*(1), 35–50.

Castelain, T., Girotto, V., Jamet, F., & Mercier, H. (2016). Evidence for benefits of argumentation in a Mayan indigenous population. *Evolution and Human Behavior*, *37*(5), 337–342 https://doi.org/10.1016/j.evolhumbehav.2016.02.002

Chater, N. (2022). The computational society. *Trends in Cognitive Sciences*, *26*(12), 1015–1017.

Choi, I., Nisbett, R. E., & Norenzayan, A. (1999). Causal attribution across cultures: Variation and universality. *Psychological Bulletin*, *125*(1), 47–63.

Clark, A., & Chalmers, D. (1998). The extended mind. *Analysis*, *58*(1), 7–19.

Creanza, N., Kolodny, O., & Feldman, M. W. (2017). Greater than the sum of its parts? Modelling population contact and interaction of cultural repertoires. *Journal of the Royal Society Interface*, *14*(130), 1–11.

Davis, H. E. (2014). *Variable education exposure and cognitive task performance among the Tsimane forager-horticulturalists* [Dissertation]. Department of Anthropology, University of New Mexico.

Davis, H. E., & Cashdan, E. (2019). Spatial cognition, navigation, and mobility among children in a forager-horticulturalist population, the Tsimané of Bolivia. *Cognitive Development*, *52*. https://doi.org/10.1016/j.cogdev.2019.100800

Davis, H. E., Gurven, M. D., & Cashdan, E. (in press). Navigational experience and the preservation of spatial abilities into old age among a tropical forager-horticulturalist population. *Topics in Cognitive Science*, 1-16.

Dennett, D. C. (2009). The cultural evolution of words and other thinking tools. *Cold Spring Harbor Symposia on Quantitative Biology*, *74*, 435–441 https://doi.org/10.1101/sqb.2009.74.008

Dennett, D. C. (2017). *From bacteria to Bach and back: The evolution of minds* (1st ed.). W.W. Norton & Company.

Derex, M., Beugin, M. P., Godelle, B., & Raymond, M. (2013). Experimental evidence for the influence of group size on cultural complexity. *Nature*, *503*(7476), 389–391.

Derex, M., & Boyd, R. (2016). Partial connectivity increases cultural accumulation within groups. *Proceedings of the National Academy of Sciences of the United States of America*, *113*(11), 2982–2987.

Derex, M., Perreault, C., & Boyd, R. (2018). Divide and conquer: Intermediate levels of population fragmentation maximize cultural accumulation. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *373*(1743),1ä16, https://doi.org/10.1098/rstb.2017.0062

DeSilva, J. M., Traniello, J. F. A., Claxton, A. G., & Fannin, L. D. (2021). When and why did human brains decrease in size? A new change-point analysis and insights from brain evolution in ants. *Frontiers in Ecology and Evolution*, *9*. 1-11 https://doi.org/10.3389/fevo.2021.742639

Deutscher, G. (2011). *Through the language glass: Why the world looks different in other languages*. Random House.

Dunbar, R. I. M. (1993). Coevolution of neocortical size, group size and languages in humans. *Behavioral and Brain Sciences*, *16*, 681–735.

Engel, D., Woolley, A. W., Aggarwal, I., Chabris, C. F., Takahashi, M., Nemoto, K., Kaiser, C., Kim, Y. J., & Malone, T. W. (2015). Collective intelligence in computer-mediated collaboration emerges in different contexts and cultures. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (pp. 3769–3778).

Engel, D., Woolley, A. W., Jing, L. X., Chabris, C. F., & Malone, T. W. (2014). Reading the mind in the eyes or reading between the lines? Theory of mind predicts collective intelligence equally well online and face-to-face. *PLoS ONE*, *9*(12), 1-16. https://doi.org/10.1371/journal.pone.0115212

Flynn, J. R. (2007). *What is intelligence?: Beyond the Flynn effect*. Cambridge University Press.

Flynn, J. R. (2012). *Are we getting smarter? Rising IQ in the twenty-first century*. Cambridge University Press.

Fullerton, M., Sloman, S., & Chan, S. (2020). Evidence for a community of knowledge across culture. In *CogSci Proceedings*.

Furnham, A., & Cheng, H. (2013). Factors influencing adult earnings: Findings from a nationally representative sample. *Journal of Socio-Economics*, *44*, 120–125.

Gershman, B. (2022). Witchcraft beliefs around the world: An exploratory analysis. *PLoS ONE*, *17*(11), e0276872.

Gershman, S. (2021). *What makes us smart: The computational logic of human cognition*. Princeton University Press.

Gigerenzer, G., & Goldstein, D. G. (1996). Reasoning the fast and frugal way: Models of bounded rationality. *Psychological Review*, *103*(4), 650–669.

Gigerenzer, G., & Todd, P. M. (1999). *Simple heuristics that make us smart*. Oxford University Press.

Goodin, R. E. (2017). The epistemic benefits of deliberative democracy. *Policy Sciences*, *50*(3), 351–366.

Gordon, P. (2005). Numerical cognition without words: Evidence from Amazonia. *Science*, *306*, 496–499.

Greenfield, P. M. (1998). The cultural evolution of IQ. In Edited by Ulric Neisser, *The rising curve: Long-term gains in IQ and related measures* (pp. 81–123). American Psychological Association.

Henrich, J. (2002). Decision-making, cultural transmission and adaptation in economic anthropology. In J. Ensminger (Ed.), *Theory in economic anthropology* (pp. 251–295). AltaMira Press.

Henrich, J. (2004). Demography and cultural evolution: How adaptive cultural processes can produce maladaptive losses: The Tasmanian case. *American Antiquity*, *69*(2), 197–214.

Henrich, J. (2016). *The secret of our success: How culture is driving human evolution, domesticating our species, and making us smarter*. Princeton University Press.

Henrich, J. (2020). *The WEIRDest people in the world: How the West became psychologically peculiar and particularly prosperous*. Farrar, Straus and Giroux.

Henrich, J., & Boyd, R. (2008). Division of labor, economic specialization, and the evolution of social stratification. *Current Anthropology*, *49*(4), 715–724.

Herculano-Houzel, S. (2016). *The human advantage: A new understanding of how our brain became remarkable*. MIT Press.

Heyes, C. (2018). *Cognitive gadgets*. Harvard University Press.

Hidalgo, C. A., & Hausmann, R. (2009). The building blocks of economic complexity. *Proceedings of the National Academy of Sciences*, *106*(26), 10570–10575.

Hidalgo, C. A., Klinger, B., Barabasi, A. L., & Hausmann, R. (2007). The product space conditions the development of nations. *Science*, *317*, 351–359.

Hollan, J., Hutchins, E., & Kirsh, D. (2000). Distributed cognition: Toward a new foundation for human–computer interaction research. *ACM Transactions on Computer–Human Interaction*, *7*(2), 174–196.

Hong, Z. (2021). Dream interpretation from a cognitive and cultural evolutionary perspective: The case of oneiromancy in traditional China. *PsyArXiv*, https://doi.org/10.31234/osf.io/kfzxs

Hooper, P. L., Demps, K., Gurven, M., Gerkey, D., & Kaplan, H. S. (2015). Skills, division of labour and economies of scale among Amazonian hunters and South Indian honey collectors. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1683), 20150008.

Humphrey, N. (1976). The social function of intellect. In P. P. G. Bateson, & R. A. Hinde (Eds.), *Growing points in ethology* (pp. 303–317). Cambridge University Press.

Hutchins, E. (1995). *Cognition in the wild*. MIT Press.

Kahneman, D. (2011). *Thinking, fast and slow* (1st ed.). Farrar, Straus and Giroux.

Kearney, M. S., & Levine, P. B. (2019). Early childhood education by television: Lessons from *Sesame Street*. *American Economic Journal: Applied Economics*, *11*(1), 318–350.

Keil, F. C. (2003). Folkscience: Coarse interpretations of a complex reality. *Trends in Cognitive Sciences*, *7*(8), 368–373.

Keil, F. C., Stein, C., Webb, L., Billings, V. D., & Rozenblit, L. (2008). Discerning the division of cognitive labor: An emerging understanding of how knowledge is clustered in other minds. *Cognitive Science*, *32*(2), 259–300.

Kempe, M., & Mesoudi, A. (2014). An experimental demonstration of the effect of group size on cultural accumulation. *Evolution and Human Behavior*, *35*(4), 285–290.

Kendal, R. L., Boogert, N. J., Rendell, L., Laland, K. N., Webster, M., & Jones, P. L. (2018). Social learning strategies: Bridge-building between fields. *Trends in Cognitive Sciences*, *22*(7), 651–665.

Kolodny, O., Creanza, N., & Feldman, M. W. (2015). Evolution in leaps: The punctuated accumulation and loss of cultural innovations. *Proceedings of the National Academy of Sciences*, *112*(49), E6762–E6769.

Laland, K. N. (2017). *Darwin's unfinished symphony: How culture made the human mind*. Princeton University Press.

Lehmann, L., Feldman, M. W., & Kaeuffer, R. (2010). Cumulative cultural dynamics and the coevolution of cultural innovation and transmission: An ESS model for panmictic and structured populations. *Journal of Evolutionary Biology*, *23*(11), 2356–2369.

Lewis, H. M., & Laland, K. N. (2012). Transmission fidelity is the key to the build-up of cumulative culture. *Philosophical Transactions of the Royal Society B-Biological Sciences*, *367*(1599), 2171–2180.

Lipschuetz, M., Cohen, S. M., Ein-Mor, E., Sapir, H., Hochner-Celnikier, D., Porat, S., Amsalem, H., Valsky, D. V., Ezra, Y., Elami-Suzin, M., Paltiel, O., & Yagel, S. (2015). A large head circumference is more strongly associated with unplanned cesarean or instrumental delivery and neonatal complications than high birthweight. *American Journal of Obstetrics and Gynecology*, *213*(6), 833.e1–833.e12.

Lutz, D. J., & Keil, F. C. (2002). Early understanding of the division of cognitive labor. *Child Development*, *73*(4), 1073–1084.

Majid, A., & Kruspe, N. (2018). Hunter–gatherer olfaction is special. *Current Biology*, *28*(3), 409–413.e2.

Martin, R. L. (2011). The innovation catalysts. *Harvard business review*, *89*(6), 82–87

May, R. M. (1997). The scientific wealth of nations. *Science*, *275*, 793–796.

McNamara, R. A., Willard, A. K., Norenzayan, A., & Henrich, J. (2019). Weighing outcome vs. intent across societies: How cultural models of mind shape moral reasoning. *Cognition*, *182*(September 2018), 95–108.

Mercier, H. (2016). The argumentative theory: Predictions and empirical evidence. *Trends in Cognitive Sciences*, *20*(9), 689–700.

Mercier, H. (2017). How gullible are we? A review of the evidence from psychology and social science. *Review of General Psychology*, *21*(2), 103–122.

Mercier, H., & Sperber, D. (2011). Why do humans reason? Arguments for an argumentative theory. *Behavioral and Brain Sciences*, *34*(2), 57–74; discussion 74–111.

Mercier, H., Trouche, E., Yama, H., Heintz, C., & Girotto, V. (2015). Experts and laymen grossly underestimate the benefits of argumentation for reasoning. *Thinking & Reasoning*, *21*(3), 341–355.

Merton, R. K. (2013). Singletons and multiples in scientific discovery: A chapter in the sociology of science. *Proceedings of the American Philosophical Society*, *105*(5), 470–486.

Meslec, N., Aggarwal, I., & Curseu, P. L. (2016). The insensitive ruins it all: Compositional and compilational influences of social sensitivity on collective intelligence in groups. *Frontiers in Psychology*, *7*, 1-7 https://doi.org/10.3389/fpsyg.2016.00676

Mesoudi, A. (2011). Variable cultural acquisition costs constrain cumulative cultural evolution. *PLoS One*, *6*(3), e18239.

Migliano, A. B., Battiston, F., Viguier, S., Page, A. E., Dyble, M., Schlaepfer, R., Smith, D., Astete, L., Ngales, M., Gomez-Gardenes, J., Latora, V., & Vinicius, L. (2020). Hunter–gatherer multilevel sociality accelerates cumulative cultural evolution. *Science Advances*, *6*(9), eaax5913.

Migliano, A. B., & Vinicius, L. (2022). The origins of human cumulative culture: From the foraging niche to collective intelligence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *377*(1843), 20200317.

Mokyr, J. (1990). *The lever of riches*. Oxford University Press.

Morand-Ferron, J., & Quinn, J. L. (2011). Larger groups of passerines are more efficient problem solvers in the wild. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(38), 15898–15903.

Moser, P., & San, S. (2020). Immigration, science, and invention. Lessons from the Quota Acts. *SSRN Electronic Journal*, 1–67 https://doi.org/10.2139/ssrn.3558718

Muthukrishna, M., Doebeli, M., Chudek, M., & Henrich, J. (2018). The Cultural Brain Hypothesis: How culture drives brain expansion, sociality, and life history. *PLoS Computational Biology*, *14*(11), e1006504.

Muthukrishna, M., & Henrich, J. (2016). Innovation in the collective brain. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1690), 1–14.

Muthukrishna, M., Henrich, J., & Slingerland, E. (2021). Psychology as a historical science. *Annual Review of Psychology*, *72*(1), 717–749.

Muthukrishna, M., Shulman, B. W., Vasilescu, V., & Henrich, J. (2014). Sociality influences cultural complexity. *Proceedings of the Royal Society B: Biological Sciences*, *281*(1774), 1–8 https://doi.org/10.1098/rspb.2013.2511

Na, J., & Kitayama, S. (2011). Spontaneous trait inference is culture-specific: Behavioral and neural evidence. *Psychological Science*, *22*(8), 1025–1032.

Nisbett, R. E., Aronson, J., Blair, C., Dickens, W., Flynn, J., Halpern, D. F., & Turkheimer, E. (2012). Intelligence: New findings and theoretical developments. *American Psychologist*, *67*(2), 130.

Nisbett, R. E., & Ross, L. (1980). *Human inference: Strategies and shortcomings of social judgment*. Prentice-Hall.

Nunn, N., Qian, N., & Sequeira, S. (2017). Migrants and the making of America: The short and long run effects of immigration during the age of mass migration. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2934211

Overmann, K. A. (2015). Numerosity structures the expression of quantity in lexical numbers and grammatical number. *Current Anthropology*, *56*(5), 638–653.

Page, S. E., Cantor, N., & Phillips, K. (2019). *The diversity bonus: How great teams pay off in the knowledge economy*. Princeton University Press.

Parise, S., Whelan, E., & Todd, S. (2015). How Twitter users can generate better ideas. *Sloan Management Review*, *56*(4), 1-7.

Perlman, E. R. (2016). *Dense enough to be brilliant: Patents, urbanization, and transportation in nineteenth century America market access*.

Pica, P., Lerner, C., Izard, V., & Dehaene, S. (2004). Exact and approximate arithmetic in an Amazonian indigenous group. *Science*, *306*, 499–501.

Pike, T. W., & Laland, K. N. (2010). Conformist learning in nine-spined sticklebacks' foraging decisions. *Biology Letters*, *6*(4), 466–468.

Pinker, S. (1997). *How the mind works*. W. W. Norton & Company.

Powell, A., Shennan, S., & Thomas, M. G. (2009). Late Pleistocene demography and the appearance of modern human behavior. *Science*, *324*(5932), 1298–1301.

Pronin, E., Lin, D. Y., & Ross, L. (2002). The bias blind spot: Perceptions of bias in self versus others. *Personality and Social Psychology Bulletin*, *28*(3), 369–381.

Rabb, N., Fernbach, P. M., & Sloman, S. A. (2019). Individual representation in a community of knowledge. *Trends in Cognitive Sciences*, *23*(10), 891–902.

Rauch, J. (2021). *The constitution of knowledge: A defense of truth*. Brookings Institution Press.

Hidalgo, C. A., Bustos, S., Coscia, M., & Simoes, A. (2011). The Atlas of economic complexity. In *Mapping paths to prosperity*.

Ridley, M. (2020). *How innovation works: And why it flourishes in freedom*. Harper.

Riedl, C., Kim, Y. J., Gupta, P., Malone, T. W., & Woolley, A. W. (2021). Quantifying collective intelligence in human groups. *Proceedings of the National Academy of Sciences*, *118*(21), e2005737118.

Ripley, A. (2013). *The smartest kids in the world: And how they got that way*. Simon and Schuster.

Ritchie, S. J., & Tucker-Drob, E. M. (2018). How much does education improve intelligence? A meta-analysis. *Psychological Science*, *29*(8), 1358–1369.

Rosati, A. G. (2017). Foraging cognition: Reviving the ecological intelligence hypothesis. *Trends in Cognitive Sciences*, *21*(9), 691–702.

Sasaki, T., Granovskiy, B., Mann, R. P., Sumpter, D. J. T., & Pratt, S. C. (2013). Ant colonies outperform individuals when a sensory discrimination task is difficult but not when it is easy. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(34), 13769–13773.

Schimmelpfennig, R., Razek, L., Schnell, E., & Muthukrishna, M. (2022). Paradox of diversity in the collective brain. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *377*(1843), 20200316.

Schniter, E., Gurven, M., Kaplan, H. S., Wilcox, N. T., & Hooper, P. L. (2015). Skill ontogeny among Tsimane forager-horticulturalists. *American Journal of Physical Anthropology*, *158*(1), 3–18.

Schniter, E., Wilcox, N. T., Beheim, B. A., Kaplan, H., & Gurven, M. (2018). Information transmission and the oral tradition: Evidence of a late-life service niche for Tsimane Amerindians. *Evolution and Human Behavior*, *39*(1), 94–105.

Seeley, T. D. (2010). *Honeybee democracy*. Princeton University Press.

Seife, C. (2000). *Zero: The biography of a dangerous idea*. Souvenir Press.

Sequeira, S., Nunn, N., & Qian, N. (2020). Immigrants and the making of America. *Review of Economic Studies*, *87*, 382–419.

Simonton, D. K. (1979). Multiple discovery and invention: Zeitgeist, genius, or chance? *Journal of Personality and Social Psychology*, *37*(9), 1603–1616.

Singh, M. (2021). Magic, explanations, and evil: The origins and design of witches and sorcerers. *Current Anthropology*, *62*(1), 2–29.

Sloman, S. A., & Fernbach, P. (2017). *The knowledge illusion: Why we never think alone*. Riverhead Books.

Sloman, S. A., & Rabb, N. (2016). Your understanding is my understanding: Evidence for a community of knowledge. *Psychological Science*, *27*(11), 1451–1460.

Sneader, W. (2005). *Drug discovery: A history*. Wiley.

Sorokowska, A., Sorokowski, P., Hummel, T., & Huanca, T. (2013). Olfaction and environment: Tsimane' of Bolivian rainforest have lower threshold of odor detection than industrialized German people. *PLoS ONE*, *8*(7), e69203.

Standage, T. (2021). *A brief history of motion: From the wheel, to the car, to what comes next*. Bloomsbury Publishing.

Starr, S. F. (2015). *Lost enlightenment: Central Asia's golden age from the Arab conquest to Tamerlane*. Princeton University Press.

Sterelny, K. (2012). *The evolved apprentice: How evolution made humans unique*. MIT Press.

Street, S. E., Navarrete, A. F., Reader, S. M., & Laland, K. N. (2017). Coevolution of cultural intelligence, extended life history, sociality, and brain size in primates. *Proceedings of the National Academy of Sciences*, *114*(30), 7908–7914.

Sulik, J., Bahrami, B., & Deroy, O. (2022). The diversity gap: When diversity matters for knowledge. *Psychological Science*, *17*(3), 752–767.

Thagard, P. (1998). Ulcers and bacteria I: Discovery and acceptance. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences*, *29*(1), 107–136.

Thierry, G., Athanasopoulos, P., Wiggett, A., Dering, B., & Kuipers, J.-R. (2009). Unconscious effects of language-specific terminology on preattentive color perception. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(11), 4567–4570.

Tomasello, M. (1999). The human adaptation for culture. *Annual Review of Anthropology*, *28*, 509–529.

Tomasello, M., Kruger, A. C., & Ratner, H. H. (1993). Cultural learning. *Behavioral and Brain Sciences*, *16*(3), 495–511.

Tversky, A., & Kahneman, D. (1973). Availability: A heuristic for judging frequency and probability. *Cognitive Psychology*, *5*(2), 207–232.

Uchiyama, R., Spicer, R., & Muthukrishna, M. (2022). Cultural evolution of genetic heritability. *Behavioral and Brain Sciences*, *45*, e152.

van Schaik, C. P., & Burkart, J. M. (2011). Social learning and evolution: The cultural intelligence hypothesis. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366*(1567), 1008–1016.

Weidmann, B., & Deming, D. J. (2021). Team players: How social skills improve team performance. *Econometrica*, *89*(6), 2637–2657.

Whiten, A., & Byrne, R. W. (1997). *Machiavellian intelligence II: Extensions and evaluations*. Cambridge University Press.

Williams, T. I. (1987). *The history of invention*. Facts on file.

Winawer, J., Witthoft, N., Frank, M. C., Wu, L., Wade, A. R., & Boroditsky, L. (2007). Russian blues reveal effects of language on color discrimination. *Proceedings of the National Academy of Sciences*, *104*(19), 7780–7785.

Winkler, M., Schulz, J., & Henrich, J. (2012). *Sociocultural diversity, surnames and innovation*.

Woolley, A. W., Aggarwal, I., & Malone, T. W. (2015). Collective intelligence and group performance. *Current Directions in Psychological Science*, *24*(6), 420–424.

Woolley, A. W., Chabris, C. F., Pentland, A., Hashmi, N., & Malone, T. W. (2010). Evidence for a collective intelligence factor in the performance of human groups. *Science*, *330*(6004), 686–688.

Yoon, J. M. D., Witthoft, N., Winawer, J., Frank, M. C., Everett, D. L., & Gibson, E. (2014). Cultural differences in perceptual reorganization in US and Piraha˜ adults. *PLoS ONE*, *9*(11), 1-8.

Youn, H. J., Strumsky, D., Bettencourt, L. M. A., & Lobo, J. (2015). Invention as a combinatorial process: Evidence from US patents. *Journal of the Royal Society Interface*, *12*(106).

Zeng, T. C., & Henrich, J. (2022). Cultural evolution may influence heritability by shaping assortative mating. *Behavioral and Brain Sciences*, *45*, e181.