Explaining Human Behavioral Diversity

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Similar chameleon magnets were initially demonstrated by Ohno *et al*. (*6*), but they operated at cryogenic temperatures (about 25 K) and required very large applied voltages (±125 V). What allowed Yamada *et al*. to produce magnetic order at room temperature (300 K) and require only a few volts to turn the ferromagnetism on and off was a clever twist on the standard FET principle (*3*, *5*, *7*). Very large electric fields can irreparably damage materials—they act like a lightning strike. The maximum carrier density that can be reversibly induced in a material occurs at a field strength known as the breakdown electric field. Yamada *et al*. incorporated an electrochemical cell into a FET and effectively increased both the breakdown field and the maximum carrier density that can be added to a semiconductor by a factor of 10. The more carriers, the more their spin can promote a robust ferromagnetic alignment that can persist at higher temperatures.

With ferromagnetic alignment in place, the challenge remains to detect it. For example, tiny magnetic nanoclusters may form and give a spurious magnetization (*1*, *8*) that is not tunable with an electric field and lacks chameleon features. The authors measured the anomalous Hall effect (AHE), first reported in 1880 (*9*), which yields a voltage (V_{AH}), or equivalently conductivity (σ_{AH}), in the direction transverse to the charge flowing through the material. With imbalance in the electron spin populations, the AHE arises from the coupling of spin and orbital properties of the carriers, which produces asymmetry of the scattering: Carriers of opposite spins ("up" or "down") are deflected in opposite directions, transverse to the charge current (see the figure, panel E). By carefully comparing AHE for samples with carrier density altered by chemical or electric field doping, the authors provide strong support for the idea that the magnetization comes from mobile magnetic messengers (*10*).

What are the next steps, and can we expect further surprises? Unlike in chameleon magnets, ferromagnetism in semiconductors can have different origins and can be independent of electric fields (*11*). To simplify quests for other chameleon magnets, complementary measurement techniques could overcome challenges associated with constant-current measurements, in which genuine material properties can become obscured if the current flows nonuniformly along an atypical path. One possible approach is to perform higher-frequency (infrared) AHE measurements (*12*), which could reduce these difficulties and directly probe how the carriers in the host semiconductor are altered with the addition of magnetic ions.

It would also be important to understand how changing the carrier density modifies the maximum temperature for the onset of ferromagnetism. The elegant spin alignment in ferromagnets tends to be fragile at elevated temperatures. Heat ruins the order of nicely aligned spins in the same way that it ruins the order in a snowflake by melting. However, with chameleon magnets, the reverse may be possible. Heating semiconductors creates extra carriers, which could strengthen their role as magnetic messengers and could conceivably overcome the usual role of heat as the main foe of ferromagnetism (*13*, *14*).

Chameleon magnets could also help us make more versatile transistors and bring us closer to the seamless integration of memory and logic by providing smart hardware that can be dynamically reprogrammed for optimal performance of a specific task (*1*, *15*). Large applied magnetic fields can enforce the spin alignment in semiconductor transistors (*16*). With chameleon magnets, such alignment would be tunable and would require no magnetic field and could revolutionize the role ferromagnets play in technology.

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BEHAVIOR

Explaining Human Behavioral Diversity

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A study of 33 nations explores the ecological, historical, and cultural foundations of behavioral differences.

People have been captivated and puzzled by human diversity since ancient times. In today's globalized world, many of the key challenges facing humanity, such as reversing climate change, coordinating economic policies, and averting war, entail unprecedented cooperation between cultural groups on a global scale. Success depends on bridging cultural divides over social norms, habits of thinking, deeply held beliefs, and values deemed sacred. If we ignore, underestimate, or misunderstand behavioral differences, we do so at everyone's peril.

When it comes to understanding these differences, getting the science right is more important than ever. Ironically, one reason that the scientific study of human thought and behavior is so daunting, fascinating, and often controversial is precisely because, more than any other species, so much of human behavior is subject to considerable population variability. To better understand both this variability and humanity's shared characteristics, in recent years researchers in the social, behavioral, cognitive, and biological sciences have been using a variety of methods (including ethnographic and historical studies, experiments, and surveys) to deepen and extend our knowledge of cultural differences. These research programs are producing quantifiable, falsifiable, and replicable results. On page 1100 of this issue, for example, Gelfand *et al*. (*1*) report on an ambitious 33-nation study that compares the degree to which societies regulate social behavior and sanction deviant behavior. It highlights differences between "tight" cultures with strong norms and high sanctioning, and "loose" cultures with weak norms and low sanctioning.

Gelfand *et al*. surveyed 6823 people in the 33 nations, asking them to rate the appropriateness of 12 behaviors (such as eating or crying) in 15 situations (such as being in a

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bank or at a party). Then, they compared the responses to an array of ecological and historical factors. Overall, they found that societies exposed to contemporary or historical threats, such as territorial conflict, resource scarcity, or exposure to high levels of pathogens, more strictly regulate social behavior and punish deviance. These societies are also more likely to have evolved institutions that strictly regulate social norms. At the psychological level, individuals in tightly regulated societies report higher levels of self-monitoring, more intolerant attitudes toward outsiders, and paying stricter attention to time. In this multilevel analysis, ecological, historical, institutional, and psychological variables comprise a loosely integrated system that defines a culture.

These findings complement a growing literature that reveals the power of the comparative approach in explaining critically important features of human behavior. For example, research suggests that the substantial variation in religious involvement among nations can be explained, in large part, by perceived levels of security. Religion thrives when existential threats to human security, such as war or natural disaster, are rampant, and declines considerably in societies with high levels of economic development, low income inequality and infant mortality, and greater access to social safety nets (*2*). Another recent investigation (*3*) suggested that past agricultural practices—specifically the adoption of the plow or the hoe by farmers—can have long-term effects on contemporary gender-related social norms and behaviors. It found that, all else being equal, societies that adopted the plow at an earlier historical period tended to have greater contemporary gender inequality (such as lower levels of women's participation in the labor market and lower percentages of women in government). In contrast, societies that adopted the hoe tend to have greater gender equality today. Gelfand *et al*.'s findings are consistent with other research suggesting that population variability seeps deep into the workings of human minds, affecting, for example, seemingly basic processes such as perception, reasoning, self-concept, distinct motivation, and cooperative strategies in economic games (*4*).

As more investigations enrich the cross-cultural database, two complex but critical questions open up for investigation. The first is: What are the causal pathways between variables (such as ecological, historical, and psychological variables), and how do they interact? Typically, for instance, researchers give causal precedence to chronologically earlier events and ecological factors, such as resource scarcity or pathogen levels, because they predate institutions, social practices, and individuals. In most cases, however, we know relatively little about the direction of causality. Do institutional structures socialize individuals to have certain values and preferences? Or do values and preferences lead to the creation of certain types of institutions? Or both? Knowledge of these pathways could shed light on a related question: How do sociocultural systems stabilize or change over time (*5*)?

Differences. Researchers are exploring the origins of the vast behavioral diversity across human population.

The second question, which researchers are just beginning to be tackle, involves the precise origins of the underlying population variation in thought and behavior, such as the differences in conformity, prosocial emotions, and intolerance of outsiders measured by Gelfand *et al*. Current evolutionary models suggest at least three distinct but compatible possibilities. The first posits that the human species is a cultural species, whose behavioral repertoire depends not only on genetic transmission but also on a sophisticated cultural inheritance system (*6*, *7*). This system causes rapid, cumulative, and divergent cultural evolution, the result of which is persistent intergroup variation in behavior, even when populations live in similar environments (*5*, *6*). The second model holds that many population differences are likely the result of different environments and represent noncultural phenotypic plasticity (*8*). Such a process could be reflected in the relationship between pathogen levels and stricter social norms reported by Gelfand *et al*. It remains to be seen, however, whether this plasticity is developmental—triggering locally adapted behavioral patterns early in an individual's life that then persist (an ontogenetic trajectory)—or whether it is "facultative," triggering locally adapted behaviors that are more flexible, and shift over an individual's lifetime in response to variation in ecological conditions. A third possibility is that some population variability originates from a process known as gene-culture coevolution (*9*). Although challenging to demonstrate conclusively, a growing research field is showing that human cultural practices directly alter parts of the human genome; the domestication of large milk-producing mammals, for instance, appears to have led to changes in gene frequencies coding for adult lactose absorption. A similar coevolutionary process may lurk behind some psychological differences, and this is an intriguing possible subject for future research. The relative contribution of these and other possible mechanisms, such as epigenetic (nongenetic) inheritance to behavioral diversity, is being actively debated (*10*).

Progress on these questions will be easier if researchers overcome two immediate obstacles facing the behavioral sciences. One is the extremely narrow cultural database that characterizes the experimental branches of psychology, economics, and the cognitive sciences, including cognitive neuroscience. Recent surveys indicate that the overwhelming majority of research participants are convenience samples selected from Western, educated, industrialized, rich, democratic (sometimes known as WEIRD) societies that often occupy one end of the broad spectrum of human behavior (*4*). Second, traditional disciplinary approaches typically focus on one level of analysis, ignoring others. As Gelfand *et al*.'s efforts illustrate, broad sampling and multiple approaches and methods are needed to investigate these different levels and their interrelations. Diverse samples, and collaborative teams that cross disciplinary boundaries (*11*), will open up new horizons in the behavioral sciences.

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