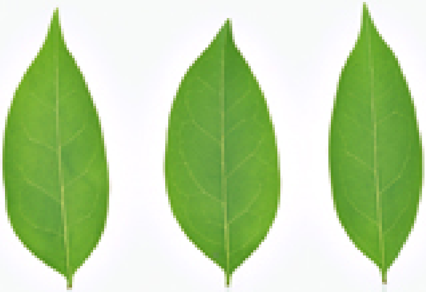

The Three Cultures

Natural Sciences, Social Sciences, and the Humanities in the 21st Century

JEROME KAGAN

Revisiting C. P. Snow

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THE THREE CULTURES: NATURAL SCIENCES, SOCIAL SCIENCES, AND THE HUMANITIES IN THE 21ST CENTURY

In 1959 C. P. Snow delivered his now-famous Rede Lecture, "The Two Cultures," a reflection on the academy based on the premise that intellectual life was divided into two cultures: the arts and humanities on one side and the natural sciences on the other. Since then, a third culture, generally termed "social science" and comprising the fields of sociology, anthropology, political science, economics, and psychology, has grown in importance. Jerome Kagan's book describes the assumptions, vocabulary, and contributions of each of these cultures and argues that the meanings of many of the concepts used by each community are unique to its methods because the source of evidence contributes to meaning. The text summarizes the contributions of the social sciences and humanities to our understanding of human nature and questions the popular belief that biological processes are the main determinant of variation in human behavior.

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Preface

On a gray March afternoon in 2006 I saw a copy of C. P. Snow's *The Two Cultures* on a shelf above the location of the two books I was searching for in the cavernous Widener Library at Harvard. Recalling the debate it provoked when published more than fifty years ago, and aware that I was looking for a theme to probe during the coming summer, I added it to the pair of books I had come to borrow. After reading Snow's essay the following weekend, it became clear that the changes in the sciences and research universities over the past half-century had rendered Snow's analysis a bit archaic, and a comparison of his views with the current reality seemed to be a worthwhile pursuit.

The most obvious change was the ascent of big science projects in physics, chemistry, and molecular biology that required expensive machines and teams of experts with varied talents and motives. The typical scientist during my graduate years went to the basement of the university building where the shop was housed and constructed himself, or had built by the department's technician, whatever apparatus was required for an experiment designed and run by the faculty member or with the help of a graduate student who assisted with the gathering and analysis of the evidence and the writing and rewriting of a paper reporting an interesting result. Two minds and four hands, often with no outside funds, performed all the work. Under these conditions the pride savored if the experiment were successful, or the blend of frustration and sadness if not, was restricted to a pair of agents.

These emotions are seriously diluted when hundreds of experts design experiments to be executed by teams visiting the international space station, preparing the Hadron Collider for probes that might reveal new particles, documenting the human genome, or studying the brain with magnetic scanners. The joy or pain felt in these settings is dispersed among many, not unlike the mood of the bank managers who bundled and sold thousands of mortgages to hedge funds in order to reduce the risk of any one of them defaulting.

The observations produced by the machines of big science have changed the ease of imagining the concepts invented to explain the mysterious signals they produced. Strings oscillating in ten dimensions, the Higgs boson, and genetic drift in a population are examples of concepts that are more difficult to imagine than concepts like bacteria, planetary orbit, molecules, or genes. A majority of scientific ideas, from Galileo to Mendel, were friendly to the human capacities for imagery and, therefore, easier to understand and to explain to a curious public.

The machines created two additional problems. Their high cost meant that investigators needed large grants from the federal government and/or private philanthropies, and only the small number of fortunate investigators working at settings with these machines would be able to make important discoveries. Thus, a young, ambitious scientist had to be at the right place in order to enjoy the advantage of these magical, powerful probes. This situation created a division between the small number of privileged investigators and the majority interested in the same question who happened to be too far from the action. The odds of a monk in an isolated monastery making a major discovery in genetics are far lower today than they were when Mendel experimented with pea plants.

It did not take long for deans and provosts to appreciate that their physicists, chemists, and biologists were bringing large amounts of overhead monies to their institutions, and they felt an obligation to reciprocate the kindness by allowing them more relaxed teaching responsibilities and a bit more respect. Predictably, many natural scientists interpreted their new status as justly earned, and a few began to display some arrogance in their pronouncements.

Snow had celebrated the natural scientists because he thought the products of their research would reduce world hunger and perhaps hasten international peace. He did not anticipate the narrative that history composed during the next two generations. Each university campus in Snow's era was a family with which many faculty members identified. When the federal government and philanthropies became major sources of research funds, hosting conferences in exotic places, many scientists shifted their primary loyalties from their institutions to these generous organizations.

The asymmetry in the largesse available to natural scientists, compared with that accorded social scientists and humanists, created status differentials that eroded collegiality and provoked defensive strategies by the two less advantaged cultures. The social scientists, whom Snow had ignored completely, had enjoyed a moment of exuberance, from about 1940 to the 1970s, when it was thought that their ideas might solve some of the stubborn problems that plagued society, especially mental illness, crime, alcoholism, and the high failure rate of school-age children growing up in economically compromised families. However, the crude synthesis of Freudian concepts with the more empirically rigorous ideas of behaviorism, on which that faith had been based, were too weak to carry their hopes to fruition. Eventually the scaffold collapsed, leaving social scientists without a protective theoretical cloak to cover their wounds or an ideological guide for the next investigation. The next cohort of social scientists, therefore, split into two groups. One rushed to join the natural scientists by studying the relations between brain activity and psychological phenomena. The biologists welcomed these new recruits, assuming they would adopt their language and conform to their rules. The larger group, who had chosen the social sciences because of a love affair with the mystery of human motives, thoughts, or emotions, rather than a curiosity about any aspect of nature that would yield its secret to a powerful mind, chose to study the complex, messier problems disturbing the public's serenity. Unfortunately, they were handicapped by a lack of powerful methods appropriate to the task and resembled farmers with pitchforks and hoes trying to grow fruit trees on a dry plateau.

The scholars who had chosen philosophy, literature, or history took a more severe beating because they were not privy to the generous grants that brought many millions of dollars to their campuses. Moreover, the public, aided by the media, had become persuaded that the answers to society's serious problems could be provided only by natural scientists. When the postmodernists, such as Derrida and Foucault, attacked the claims made by members of their own intellectual family, the loss of confidence among humanists became catastrophic.

The civil protests of the 1960s, which Snow did not anticipate, contributed to an ethic of political correctness in which justice began to compete with individual merit. Deans, research review committees, and honorary societies decided it was important to try to divide their rewards in rough correspondence to the population proportions for gender, ethnicity, and region of the country. Fairness was to be added to talent and motivation as a relevant criterion when promotions, honors, and grant funds were allocated. All of these events sculpted new structures and procedures that Snow might not recognize. Newton would have been astonished.

I had written favorably on Bohr's suggestion that the meaning of every scientific concept depended on its source of evidence. The natural sciences, social sciences, and humanities often used the same word to name different phenomena, and therefore a word could have different meanings in the three communities. Many failed to appreciate that the neuroscientists' understandings of the terms "consciousness," "fear," and "memory" were not shared by social scientists or humanists using the same vocabulary. Thus, scholars and the larger public had to be reminded that each of the intellectual communities had something important to contribute to an understanding of human nature and societies.

These reflections motivated this brief book, which had three primary goals: to analyze the meanings of the vocabularies used by the three cultures, to describe and critique the seminal assumptions the three communities bring to their work, and, finally, to list each group's unique contributions. The first chapter considers the differences among the cultures in their vocabularies, mental tools, and balance of interest in patterns or single features; the influence of history on problems probed; and, finally, the motive hierarchies of each group. The second chapter analyzes the natural sciences, especially their four seminal premises, their wish to avoid an entanglement with ethics, their insistence on minimizing the differences between humans and other animals, the challenges to their prior hegemony, and the ambivalence among youths interested in natural science toward research that requires team cooperation.

The next two chapters on the social sciences consider the initial reluctance to regard collectives as legitimate phenomena, the problems with their metrics and methods, the loss of confidence following the dramatic advances in biology, the problems surrounding the formal models of economists, and also the significant contributions of social scientists.

The penultimate chapter explains the loss of status among humanists following the ascent of the social sciences and the postmodernist challenge to the validity of claims based on narratives, as well as their seminal contributions to an understanding of the human condition. The final chapter describes the recent disturbing developments in the university, especially the diluted identification with the institution, the crass search for celebrity, and the confusion over the current mission in undergraduate education. The final pages turn skeptical by asking whether life on this planet is better today than it was 200 years earlier and fails to arrive at an unequivocally affirmative reply. The text ends with a plea to all three communities to recognize the special forms of enlightenment each brings to a world of diverse societies. I hope readers will find something of interest in an effort that taught me more than I anticipated when I took Snow's paperback from the library shelf.

I thank Robert Le Vine, Steven Reznick, and Jay Schulkin for comments on the full text, Gerald Holton for a critique of the chapter on the natural sciences, and David Warsh for patiently re-reading many versions of the section on economics. I am indebted to Nancy Snidman, Paula Mabee, and Sabiha Imran for help with manuscript preparation; to Eric Schwartz, now at Princeton University Press, for being my advocate with the Syndics at Cambridge University Press; and to Terry Kornak for editing of the text.

1

Characterizing the Three Cultures

The influential British novelist and science administrator C. P. Snow, who had trained as a natural scientist, published a lecture delivered in Cambridge University in 1959 titled "The Two Cultures." The lecture and the fifty-one-page book that followed provoked heated discussion because of its brash dismissal of the humanities as an intellectual mission lacking in rigor and unable to contribute to the welfare of those living in economically underdeveloped regions. Not surprisingly, humanists resented Snow's allegations that world peace and prosperity would profit from training more scientists and engineers and fewer historians, philosophers, and literary critics. Three years later, F. R. Leavis, an admired literary critic at Cambridge University, delivered an unusually harsh, occasionally impolite, rebuttal that caricatured Snow as a failed chemist, incompetent novelist, and social commentator who was ignorant of the world's serious problems.

Snow composed his essay as America was about to experience an extraordinary expansion in higher education that led to a fourfold increase in faculty (from 250,000 to more than 1 million) and a sevenfold increase in students to a total of 15 million, compared with only 50,00 Americans who were attending colleges in 1870.[1] These changes were due primarily to the establishment of new community colleges and rising enrollments in state universities trying to accommodate the many World War II veterans who, assisted by the government's decision to subsidize their education in gratitude for their service, chose to attend college rather than return to the working-class jobs held by their fathers.

There was a proportionate swelling in the funds available for research and in the numbers of scientists, research administrators, practitioners, journalists, and teachers managing, utilizing, disseminating, or teaching the products of science. More than 5 million scientific papers were published worldwide from 1992 to 2002, and 40 percent of that very large number were written by American investigators.[2] Most youths who choose a life in science in 2009 do not appreciate that the term *scientist* (as distinct from a physician or philosopher), as well as the opportunity to pursue a research career independent of one's social class or ethnicity, are less than 170 years old. These facts, combined with a public that had become more skeptical of select scientific claims and the idealistic depiction of scientists as pure of motive in their pursuit of truth, invite a re-examination of Snow's bold thesis.

Although the primary concerns, sources of evidence, and concepts remain the most important nodes of difference among natural scientists (physicists, chemists, and biologists), social scientists, and humanists, the three communities vary on six additional dimensions less pertinent to their epistemologies. (I consider the investigators who study the biological bases for, or evolutionary contributions to, animal or human behavior as natural scientists.) The nine dimensions follow:

1. The primary questions asked, including the degree to which prediction, explanation, or description of a phenomenon is the major product of inquiry
2. The sources of evidence on which inferences are based and the degree of control over the conditions in which the evidence is gathered
3. The vocabulary used to present observations, concepts, and conclusions, including the balance between continuous

properties and categories and the degree to which a functional relation was presumed to generalize across settings or was restricted to the context of observation

4. The degree to which social conditions, produced by historical events, influence the questions asked
5. The degree to which ethical values penetrate the questions asked and the conclusions inferred or deduced
6. The degree of dependence on external financial support from government or industry
7. The probability that the scholar works alone, with one or two others, or as a member of a large team
8. The contribution to the national economy
9. The criteria members of each group use when they judge a body of work as elegant or beautiful

Most intellectual efforts consist of three components: (1) a set of unquestioned premises that create preferences for particular questions and equally particular answers, (2) a favored collection of analytical tools for gathering evidence, and (3) a preferred set of concepts that are the core of explanations. A naïve observer who held no premises about the nature of solid objects might conclude that the bottom half of a pencil resting in a half-filled glass of water had been bent by the liquid. Social scientists and humanists share more premises, analytic tools, and concepts, as well as more of the other criteria in Table 1, than each does with natural scientists. Natural scientists emphasize material processes, minimize the influences of historical and cultural contexts and their associated ethical values, and are primarily concerned with the relations between a concept and a set of observations. Social scientists and humanists resist awarding biology too much influence, rely heavily on semantic networks and, therefore, are often as concerned with the relations among a set of semantic terms as they are with the relation between a concept and evidence, and frequently seek answers that affirm or disconfirm an

TABLE 1. *Comparison of the three cultures on nine dimensions*

Dimension	Natural Scientists	Social Scientists	Humanists
1. Primary interests	Prediction and explanation of all natural phenomena	Prediction and explanation of human behaviors and psychological states	An understanding of human reactions to events and the meanings humans impose on experience as a function of culture, historical era, and life history
2. Primary sources of evidence and control of conditions	Experimentally controlled observations of material entities	Behaviors, verbal statements, and less often biological measures, gathered under conditions in which the contexts cannot always be controlled	Written texts and human behaviors gathered under conditions of minimal control
3. Primary vocabulary	Semantic and mathematical concepts whose referents are the material entities of physics, chemistry, and biology, and assumed to transcend particular settings	Constructs referring to psychological features, states, and behaviors of individuals or groups, with an acceptance of the constraints that the context of observation imposes on generality	Concepts referring to human behavior, and the events that provoke them with serious contextual restrictions on inferences
4. The influence of historical conditions	Minimal	Modest	Serious

Dimension	Natural Scientists	Social Scientists	Humanists
5. Ethical influence	Minimal	Major	Major
6. Dependence on outside support	Highly dependent	Moderately dependent	Relatively independent
7. Work conditions	Both small and large collaborations	Small collaborations and solitary	Solitary
8. Contribution to the national economy	Major	Modest	Minimal
9. Criteria for beauty	Conclusions that involve the most fundamental material components in nature inferred from evidence produced by machines and amenable to mathematical descriptions.	Conclusions that support a broad theoretical view of human behavior.	Semantically coherent arguments described in elegant prose.

implicit ethical ideal. However, the meanings of the concepts used by the three groups deserve special attention because the communities use different sources of evidence.

THREE VOCABULARIES

The meaning of a sentence, for speakers and listeners, is based on the actual events that are named, as well as the network of ideas that was the origin of the statement. The meaning of the declaration, "The bulls were beaten yesterday" depends on whether the referents for bulls were animals or the Chicago basketball team. The three cultures represent language communities that impose distinct meaning networks on their important concepts and, like the dispersed Indian groups of fifth century Meso-America, compete with each other for dominance. One of the insights of the twentieth century, due in large measure to Ludwig Wittgenstein, is that the meanings of most statements are not transparent. Application of this idea to a scientific proposition implies that meaning depends on the specific observations to which a statement refers, and, therefore, the procedure that generated the evidence and the web of meanings that define a theory.

The vocabularies of each culture contain a number of concepts with technical definitions that are of primary interest to only one group (e.g., gluon and transposon for natural scientists, attribution error and gross domestic product for social scientists, and antinomy and historical era for humanists). The vocabulary of psychoanalysts attributed a unique meaning to *energy* that was neither the one implied by the Chinese concept *ch'i*, nor the meaning physicists understood in the principles of thermodynamics. But the three cultures also use terms with exactly the same sound and spelling that have different meanings for each culture, even though the scholars may not recognize that fact. The terms *fear*, *capacity*, *arousal*, *memory*, and *count* are examples. The meaning of "fear" in T. S. Eliot's line: "I'll show you fear in a handful of dust" is not the meaning intended by the social scientist who writes that "The heritability of realistic fears is less than the heritability of unrealistic fears," nor the meaning understood by the biological scientist who states that "Rats that stop moving when they hear a tone that had predicted electric shock are in a state of fear."

Even though the poet, psychologist, and biologist use the same word, each is naming a distinctly different phenomenon. Eliot was naming the subjective feeling that pierced consciousness when he reflected on the value confusion and spiritual emptiness that permeated Europe after World War I. The psychologist was referring to the answers of adults filling out questionnaires asking them about their sources of worry. The biologist was describing a rat's immobility in response to a conditioned stimulus that had signaled an unpleasant event in the past. Eliot could have used the word *angst*; the psychologist could have used the word *worry*, and the neuroscientist could have used the term *vigilant*.

The descriptions of a hypothetical person called Max make this point clearly. Natural scientists would use a vocabulary that referred to features like bone density, glucose level, blood flow, and electrical currents in body and brain. Social scientists would describe Max's identifications with his family, gender, ethnicity, and nation; the shame he feels as an American over the deaths of innocent Iraqi citizens; and childhood memories of family holidays at the seashore. Humanists would refer to his membership in a family that migrated from Ireland to America in the nineteenth century, his nostalgia for summer when the November trees are bare, and the blend of powerlessness and melancholy that pierces consciousness when he reflects simultaneously on his aging father and Dylan Thomas's line, "Do not go gently into that good night." None of these three descriptions can be translated into one of the others without losing some meaning.

The first cohort of economists treated the physicists' meaning of *capacity* in the sentence, "Energy is the capacity to do work" as similar to its meaning in "Money is the capacity to purchase goods." As a result, they assumed that the equations of thermodynamics might be appropriate in mathematical models of the economy. They failed to appreciate that many predicates assume different meanings when they are joined to different nouns because the validity of every declaration rests with a full sentence rather than with a single word. The predicate *fall*, for example, has four distinct meanings in each of the four expressions: "Temperatures fall," "Prices fall," "Apples fall," and "Spirits fall."

Even some terms in the vocabulary of natural scientists have different meanings. The meanings of mass, space, and time in Newton's equations are not synonymous with the meanings that Einstein understood. Nonetheless, Newton's concepts work well for an apple falling from a tree and Einstein's terms explain the energy emitted from a fissionable uranium atom. Acceptance of relativity theory and quantum mechanics during the last century, which altered the traditional meanings of time, space, and objects, allowed both philosophers and scientists to appreciate that the meaning and validity of every proposition are restricted to the language system to which it belongs, and might not be valid in another system.

A tolerance toward multiple meanings for words belonging to distinct language systems allows us to believe, simultaneously, that physicists writing in the mathematical language of quantum mechanics are correct when they declare that there are no stable objects in the world, and psychologists are correct when they state that the world consists of solid objects like cups, that can be touched, moved, and filled with liquid. We accept both statements as true without the disturbing feeling of cognitive dissonance that accompanies logically contradictory ideas because they belong to separate language systems. This principle allows neuroscientists to use the word *fear* to describe a pattern of neuronal activity and psychologists to use the same word to describe a person's judgment of his or her subjective experience, even though the term *fear* has different meanings in these two language networks.[3] Unfortunately, many scientists experience more cognitive dissonance in this instance than they do in the case of the reality of cups.

The evidence gathered by biologists and psychologists awards different meanings to the term *aroused*. Most adults report that the color red induces a feeling of arousal or excitement, whereas blue reduces the intensity of subjective arousal. However, the brain wave profiles that are indicative of enhanced arousal of cortical neurons occur to blue rather than red. Thus, neuroscientists should not equate the arousal that is defined by a pattern of cortical activity with the psychological experience of arousal.[4]

This same argument applies to *memory*. A group of Chinese adults who had been exposed to Chinese during early childhood, but had consciously forgotten their first language after learning English as a second language, indicated whether the second word in a sequence of two English words was or was not semantically related to the first; for example, dog and cat are related but dog and crayon are not. The neurons of the temporal lobe generate a distinctive wave form in the electroencephalogram when a second word is semantically unrelated to the first about three-tenths of a second before consciousness recognizes that the second term is incongruent.[5]

The bilingual Chinese who were convinced that they lost their childhood knowledge of Chinese showed a smaller than expected wave form when a second word was unrelated to the first in English, but happened to share a Chinese character. The English words *train* and *ham* are unrelated, but share the Chinese character *huo*. Thus, when the word *ham* appeared after *train*, the bilingual Chinese person showed a smaller wave form to ham than did monolingual English speakers, even though they were totally unaware of the fact that their brains had responded to a shared meaning that was unavailable to their consciousness.[6] This fact implies that their brains had preserved some feature of the meanings of the Chinese characters and, therefore, the terms *memory* and *remember* have different meanings when a brain response or conscious detection of meaning supplies the evidence. Psychologists invented the concept of implicit memory to account for this fact.

The term *count* provides a third example of the conceptual confusion that occurs when neuroscientists use brain profiles to define a concept that is essentially psychological. Although this term was invented originally to represent the ability to arrange the cardinal numbers in an ordinal sequence, two neuroscientists concluded that brains can *count* because the profiles of activation were different for displays of 20 compared with 30 dark circles.[7] However, the brain was responding to the perceptual difference in the spatial distribution of distinctly contoured elements and not to their number. A person gazing at a shelf containing eighteen books sees an array of objects varying in height, width, and color, not eighteen objects. Infants see the protuberances on their hands; it will be several years before they learn that each hand has five fingers. The blood flow patterns that are normally activated when people are counting were dissimilar to two displays of three objects in different spatial arrangements (one array grouped two of the objects close together and the other did not). If the neurons in this area were counting, the blood flow patterns should have been the same because both arrays had exactly the same number of objects.[8] Moreover, the areas that are active when people are looking at arrays of discrete objects are different from the areas that are active when people are reading numbers.[9] The brain would respond differently to clocks set at 6:00 and 3:00 o'clock, but that does not mean that the activated neurons were responding to the concept of time. Number and time are acquired concepts imposed on experiences, and appreciation of their meanings relies on circuits involving distinct brain sites.

Most living forms, including algae, display a regular twenty-four- to twenty-five-hour cycle of metabolic activity, but biologists do not suggest that algae are "counting" the passing minutes of each day. Neither are foraging bees, whose dance on returning from a bed of flowers to their hive varies as a function of distance between the hive and the flowers, counting the meters between the two places. It turns out that their nervous system is registering the amount of contour they fly over on their visit to the flowers and the accompanying variation in neural activity determines the quality of the dance.[10] Bees also scatter the pollen of the plants they visit, but that fact does not mean that they are altruistic or "good Samaritans." The hair cells on the basilar membrane of the inner ear respond differentially to sounds of varying frequencies, because of the inherent variation in their structure, but these tiny sensory receptors are not "counting" the frequencies in the incoming stimulation. The ability of neuronal clusters to react differentially to varied numbers of objects within the first one-fifth of a second is an intriguing phenomenon worthy of study, but this fact does not mean that neurons or brains are "counting." The neurons of the primary auditory cortex of the ferret respond as humans do to sounds that represent varied English phonemes, but it would be a semantic error to say that the ferret is responding to the components of human speech.[11]

A study of brain development in a large, representative sample of American children and adolescents from many cities and varied social class backgrounds reveals the stubborn fact that the meaning and validity of an inference referring to a psychological state always depend on the source of evidence. The scientists gathered information on changes in the human brain across more than a decade of development. One surprising finding was the absence of dramatic differences in patterns of brain growth among children who were members of families from divergent social classes.[12] This observation is puzzling because social class is, far and away, the best predictor of a child's IQ score, vocabulary, grades in school, the probability of mental illness, gang membership, violent aggression, and a criminal record in every society that has been studied.[13] If investigators had to predict the vocabulary, academic achievements, number of arrests for criminal activity, and number of bouts of depression in 500 adults, and could choose either the educational level and vocation of their family of rearing or measurements of their brain, those who selected the person's social class would be more accurate.[14]

THE CASCADE OF EVENTS

The critical point is that the vocabulary biologists use to describe the brain's properties does not, at least at present, correspond closely in meaning to the vocabularies used by social scientists and humanists.

The latter two disciplines describe the late phases of a cascade that begins in a series of brief neuronal events and ends in a perception, thought, feeling, or behavior that lasts for a longer time.[15] That is, an intention to get up and go to the refrigerator to find food lasts much longer than any of the brain states that occur during the time that transpired between the original idea and opening the refrigerator.

Different metrics apply to the phases of a cascade that began with the response of a single neuron and proceeded to the activity of a cluster of neurons, a circuit, a network of circuits, and, finally, to a psychological outcome. The activity of a single neuron is usually measured in terms of the frequency of spike potentials (i.e., firing of the cell). The metric for a cluster of neurons is usually the number or proportion firing at the same frequency. The metric for a circuit is usually coherence (meaning the correspondence between the frequency spectra at two different sites), and the metric for a network of circuits is the probability of co-activation. The metrics for psychological outcomes include the frequency, speed, or accuracy of a response; the duration of a perception, emotion, or thought; the clarity of a representation; and the valence and intensity of a feeling. These metrics cannot be translated into any of the preceding ones.

A documented illustration of this principle involves the unexpected discovery that young rat pups separated from their mothers for a brief interval become adults that cope with certain stressors better than those that did not experience the separation. At least three phases intervene between the separation and the adult behavior. The first phase refers to the consequences of the fact that rat mothers are likely to lick and groom a separated infant, whose skin is cooler, with more vigor than they display with a pup that was not separated. The more vigorous licking affects the pup's genome by preventing the methylation of a specific nucleotide in the promoter region of the gene responsible for a class of receptors in the hippocampus that is activated by the hypothalamic–pituitary–adrenal axis (HPA axis). Because methylation usually leads to less efficient expression of the gene, the gene in the licked infants is more fully expressed than in the pups that were licked less vigorously. The phenomena of this initial phase are described with terms referring to the four nucleotides that comprise DNA, the process of methylating one of them, and the degree of expression of that gene. The words for the second phase refer to the protein receptors located on select neurons in the hippocampus. The possession of a dense set of receptors means that there will be feedback to the neurons of the HPA axis that results in a dampening of HPA activity and, therefore, modulation in the secretion of the molecules that lead to behavioral signs of a state of stress. The words for this third phase refer to feedback mechanisms, the molecule corticosterone, and states of stress. Thus, we need three distinct vocabularies to explain why a separated rat pup becomes an adult that is less avoidant and less "fearful" of challenge and novel environments. (It is intriguing to wonder whether there might be a comparable process in human infants; for example, do human mothers who caress their infants a great deal provoke an analogous phenomenon in the brains of their children?) The important point is that the vocabulary that describes each of the phases in any cascade that begins with a genetic or brain event and ends with a behavior has some degree of autonomy.

Even a behavior as serious as an adolescent's suicide is influenced, at least in America, by the individual's social class (more common among the poor), region of the country (more common in less densely populated areas in the western states), time of year (more prevalent in spring and summer), and day of the week (suicides are most common on Monday).[16] Thus, neuroscientists do not add much clarity to the psychological concept of *self* when they suggest that it is a pattern of coherence in neural activity.[17] One cannot see a forest while inside it. One cannot understand the psychological state of a depressed person who describes her inner world as dark, devoid of energy, and hungering for a silence that is free of the noise of crowds by remaining within a vocabulary that refers only to biological processes.

The critical point in this discussion is that the concepts in the social sciences and the humanities refer to emergent phenomena that cannot be described with the vocabulary used by natural scientists. The timbre of a violin sonata cannot be translated into the physicist's terms for frequency, intensity, and time; the balance in a Monet painting cannot be translated into sentences referring to color, contour, or shape; and, as noted, the meaning psychologists attribute to the terms *remember*, *count*, or *fear* cannot be replaced with statements referring only to brain states or structures. Put simply, the phenomena that humanists and social scientists describe represent special combinations of events that require their own vocabulary. Physicists confront a similar problem. The world of quantum processes is probabilistic and discontinuous, whereas the masses of several stones and their accelerations when struck with a known force are certain and continuous. There is a fuzzy boundary between these two worlds, which require different vocabularies, and physicists do not yet understand how objects and their functions emerge from a quantum world. Neuroscientists do not yet understand how perceptions, thoughts, feelings, and actions emerge from the activity of neurons.

An explanation is satisfying when investigators can imagine what is happening at each transition in a cascade and cannot think of another way to account for the transitions.[18] An understanding of the relations between phases has been most successful when scientists concentrated on contiguous phases (e.g., the relation between genes and neurochemistry or between brain chemistry and moods), and less successful when they skipped phases and tried to understand the relations between genes and particular moods because variations in life history influence the emotional profiles of individuals with the same gene.

Biological and social scientists focus on different phases, or halfway houses, in the complete cascade that defines an observed phenomenon. Therefore, the three cultures think about the same event in different ways. Their perspectives are analogous to the incompatible perceptions of a drawing that can represent either a young or old woman as a function of where viewers focus their attention. Each perspective has consistency and coherence within each of the language communities, but not always across communities. This suggestion would not bother mathematicians, who understand that a mathematical idea, like infinity, can assume different meanings in different mathematical arguments. Similarly, the meaning of *population density* in the United States depends on whether one computes the ratio of the total population to the total geographical area or the ratio of the number of individuals living in areas where most Americans live over that more restricted area. The first estimate of 70 people per square mile implies a low population density; the second ratio of 3,000 per square mile evokes a different image.[19]

TROPES

There is one more reason for the ambiguity that surrounds the meanings of words. Humans have an automatic tendency to relate two or more networks for different concepts and detecting, with minimal effort, a single semantic node that is shared between or among them. When the shared node awards a nonliteral meaning to the concept, as in the metaphor "humans are gorillas," it is called a trope. The features of concepts vary in their essentialness or defining property. For example, the ability to fly is a defining property of birds, whereas the ability to catch fish is a secondary property. Most tropes, or metaphors, are satisfying when a defining property of the second term is a secondary property of the first term. Hence, the metaphor "Humans are gorillas" is acceptable because the capacity for aggression is a primary feature of gorillas but a secondary feature of humans. Hence, the statement "Gorillas are humans" is not a satisfying metaphor. Tropes can be categorized as satisfying or unsatisfying, coherent or incoherent, but cannot be evaluated as true or false. Only novelists and poets are permitted to describe April as cruel or jealousy as the green emotion. Most Americans have acquired the semantic nodes helpless, weak, and uncontrolled as defining features for the network *baby*. Hence, an American adult who was called a baby is likely to feel insulted because the features helpless, weak, and uncontrolled are inconsistent with the nodes representing the literal understanding of *adult*. The node for *beast* is primary in the Japanese network for *monkey*, but not in the network possessed by most Americans.[20] Thus, a Japanese person who is called a monkey is more likely than an American to become angry.

Scientists often treat a novel scientific advance as a fruitful trope, or metaphor, for body, brain, or mind. For example, Descartes regarded the machine as a metaphor for bodily function; Freud exploited the metaphor of energy for emotional processes; twentieth-century scientists were friendly to a computer metaphor for thought; and contemporary investigators, awed by the recent advances in neuroscience and genetics, treat modularity as a metaphor for psychological functions. Each of these metaphors is misleading, for neither clocks, steam engines, computers, nor genes provide accurate models for the nature of brain processes or psychological activity. Although metaphors can be initially helpful crutches for creativity, scientists must remain eternally vigilant to the dangers of their seductive appeal.

The languages of the social sciences and humanities acknowledge the influence of tropes, but natural scientists typically ignore nonliteral meanings because they often include a perceptual representation and a feeling that resist accurate measurement and cannot be classified as true or false. Sentences that are interpreted literally are accompanied by patterns of brain activity that differ from the profiles accompanying a metaphorical reading of the same sentences because perceptual representations preferentially activate the right hemisphere. When individuals are interpreting sentences literally the left hemisphere is more active and there is less right hemisphere involvement.[21] Many neuroscientists measuring the brain's reaction to pictures of infants or monkeys assume that all the participants perceived and interpreted the scenes in the same literal way. Because they do not, there is extraordinary variation in the brain profiles provoked by most incentives. Natural scientists prefer to assign the cause of this variation to material differences in the brains of the participants, rather than to the meanings of the tropes they might have imposed on the stimuli.

A Brief Summary

Every concept has multiple features and these features can change with time. Therefore, the validity of any claim that two concepts are similar, or closely related, depends on the specific features that are presumed to be similar. An investigator should not treat one concept as equivalent to another if only a small number of all the possible features are the same. If a scientist writes that fatigue renders a person vulnerable to illness, readers need to know whether the primary feature for fatigue was the state caused by insomnia or excessive exercise, and whether the seminal feature for illness was a bacterial infection or a torn hamstring muscle.

This issue is especially relevant for the scientists who write computer programs simulating cognitive processes, an effort called artificial intelligence or AI. These programs typically consist of symbols for words without schematic representations of bodily states or the products of perception. As a result, these programs would represent the concept *animal* by listing the primary semantic features of this category, including reproduction, respiration, digestion, locomotion, growth, and death, but would fail to include perceptual schemata for a shark's attack on a person or a dog's obedience to a command and the feelings these schemata evoke. Yet, these representations are part of the average person's representation of the concept *animal.*

Many scientists studying the relation between brain and psychological states fail to honor this principle. For example, some write that activation of the amygdala in adults expecting a brief electric shock to their fingers means that the individuals are fearful. The problem with this conclusion is that scientists do not restrict the truth value of this claim to amygdalar activation in this specific situation, but imply that any time the amygdala is activated by any event that could be construed as "threatening" the person is in a state of fear. Even if adults deny feeling any fear in response to a still photograph of a face with a fearful expression, many neuroscientists assume that they are in a state of fear because their amygdala was activated. This inference ignores the equally reliable fact that the amygdala is also activated whenever a person encounters any event he or she did not expect, whether a sign of danger or a signal for food or sex. Most individuals do not encounter people walking around with fearful facial expressions; hence, it is reasonable to argue that their psychological state should be described as surprise or uncertainty, rather than fear. Moreover, the amygdala consists of several neuronal clusters with different evolutionary histories and different connections to the rest of the brain. Each of the amygdala's separate neuronal clusters displays a distinct profile of activation to different kinds of threat (e.g., a tone signaling electric shock and the smell of a natural predator produce different profiles in animals).[22] Hence, there is more than one type of "fear." It is also odd that, after puberty, men have a larger amygdala than women, but males are less, not more, likely to develop phobias and anxiety disorders.[23] We have a long way to go before we understand the relations between the sentences that describe brain function and those descriptive of psychological phenomena.

I borrow an example from the late Thomas Kuhn to make the critical point that many words used by natural and social scientists belong to different semantic networks and, therefore, are not equivalent in meaning. The French word *doux* (or *douce*) refers to the taste of honey, a soft touch, bland tasting soup, a tender memory, or a gentle breeze. The English word *sweet* also refers to the taste of honey, but, in addition, to a victory, a beloved, and the middle strings of a tennis racquet, but not to bland soup. Because meaning derives from the total network of related terms the French word *doux* and the English term *sweet* do not have identical meanings. The same conclusion applies to terms like fear, aroused, and count in the vocabularies of neuroscientists and psychologists and for the same reason.

THE INFLUENCE OF HISTORY

The balance between inquiries guided by a search for generalizations that transcend the current historical moment and those seriously influenced by the temporary conditions historical events created differentiates the three cultures. The present moment is part of two sequences that have never occurred before and will not be repeated. The oldest narrative began several billion years ago with the first living things. Although physicists believe that the nature of, and relations among, the constituents of matter present right after the Big Bang were different from those operative today, and biologists recognize that the genomes of humans who lived 100,000 years ago were both different from and less variable than those of contemporary humans, most of the problems natural scientists pursue are affected less seriously by the vicissitudes of time than those posed by social scientists and humanists.

The later sequence began about 10,000 years ago when human populations began to increase in size and to leave some record of their social organization, experiences, and skills. This narrative is characterized by changes in beliefs, sources of uncertainty, and social organizations. Although many social scientists seek to understand the universal human phenomena of perception, memory, language, emotion, learning, group formation, and affiliation with principles that are not restricted to the current historical moment, an equally large group probes phenomena more seriously influenced by current societal conditions.

The most important changes in Europe and America during the hundred years from 1760 to 1860 were the emergence of