

CHAPTER 5

Biology, Evolution, and Psychological Development

GARY GREENBERG

Professor Emeritus, Wichita State University

TY PARTRIDGE

Associate Professor, Department of Psychology

WHAT IS PSYCHOLOGY?	115
A RELATIONAL DEVELOPMENTAL SYSTEMS APPROACH	117
BIOLOGICAL FACTORS IN BEHAVIORAL DEVELOPMENT: EVOLUTION AND GENETICS	118
Evolution	118
Genetics—The Mechanism of Evolution?	125
BIOLOGICAL FACTORS IN BEHAVIORAL DEVELOPMENT: THE BRAIN AND NERVOUS SYSTEM	127

Brain and Mind	128
Contemporary Neuroscience and Its Problems	130
BIOLOGY AND DEVELOPMENT	135
Role of the Gene in Development	137
Development in Complex Adaptive Systems	138
Psychology Is a Developmental Science	139
CONCLUSIONS	142
REFERENCES	142

WHAT IS PSYCHOLOGY?

Taking a cue from Alice in Wonderland, we always believe it is best to start at the beginning. Thus, we start this discussion of the relation of biology to psychology with an understanding of the nature of the science of psychology. Succinctly, Psychology is the biopsychosocial science of animal behavior. Animal behavior is included to avoid references to other uses of the term, such as the physicist's description of the behavior of particles. Furthermore, the implication here is that only animals behave in the psychological sense; in addition, we believe that behavior requires a nervous system, again restricting psychological behavior to animals. The idea that plants can behave in the psychological sense rears its head every so often and is quickly dismissed: "The past three years have witnessed the birth and propagation of a provocative idea in the plant sciences. Its proponents have suggested that higher plants have nerves, synapses, the equivalent of a brain localized somewhere in the roots, and an intelligence" (Alpi et al., 2007, p. 135; see also Dudley & File, 2007). This same

sentiment can be extended to recent developments in the realm of artificial intelligence and naturalistic theologies such as the Gaia hypothesis (Lovelock, 1979). The adaptive behavior of complex systems and neural network computing systems are qualitatively different than psychology.

Implied by the perspective that psychology is the biopsychosocial science of behavior is the assumption that behavior is influenced by biological, psychological, and social factors, among others. In this context, it is critical to understand the significance of the important organizing principle of integrative levels: "a view of the universe as a family of hierarchies in which natural phenomena exist in levels of increasing organization and complexity" (Aronson, 1984, p. 66). This is a refutation of atomistic/reductionistic principles and an affirmation of holism—that wholes cannot be reduced to their parts; that "more is different" (Anderson, 1972; Kauffman, 2007; Overton, 2006). Indeed, "hierarchy is a central phenomenon of life. Yet it does not feature as such in traditional biological theory" (Vrba & Eldredge, 1984, p. 146). Psychology is one

of a growing number of areas of study falling under the metasciences of holism and complexity.

Psychology, then, is a more complex science than is biology, and sociology more so than is psychology (Cole, 1983; Feibleman, 1954). Although a student may struggle more through her physics class, psychology can be seen to be more complex than is physics, which not only can describe its phenomena with equations but can identify the variables on both sides of those equations. Psychology, of course, has not yet identified all variables pertinent to understanding behavioral origins. Nevertheless, psychology is a science sufficiently mature to stand on its own as unique, and not as a subset of biology (Greenberg, Partridge, Mosack, & Lambdin, 2006; Kantor, 1959; Schneirla, 1949), the discipline from which it emerged. A similar situation existed with regard to biology in the early 1900s when Woodger (1929) argued that biology needed an explanatory model distinct from physics and chemistry. This was a mere 120 years after the “founding” of biology as the “science of life” by Lamarck (Keller, 2002). Similarly, psychology is presented as a unique science, separate and distinct from biology, with its own unique principles, searching for its own unique laws. Notably, this has been recognized by scientists other than psychologists. The physicist P. W. Anderson, for example, has said: “At each stage [i.e., level of organization] entirely new laws, concepts, and generalizations are necessary. Psychology is not applied biology, nor is biology applied chemistry” (1972, p. 393). The ecologist Vincent Bauchau (2006) points out that just as there are principles in biology that do not belong to physics, so there are principles in the other sciences, from chemistry to psychology, that cannot be reduced and that do not belong to sciences lower in the hierarchy. Natural selection, for example, a “universal law of biology,” cannot be reduced to physics. Of course, the idea of a hierarchy of the sciences is not new. That the sciences themselves can be divided into areas of study based on qualitative changes in complexity of organization, with physics and chemistry addressing the lower levels of complexity, and biology, psychology, and sociology addressing higher levels of complexity, is an idea that seemingly was originated by Auguste Comte in the late 1800s (see Boorstein, 1998, p. 223) and was later developed by others such as Novikoff (1945) and Feibleman (1954). The study of learning, of cognition, of personality development, and of species-typical behaviors are subject areas that the psychologist can address from the orientation proposed here—from the perspective of psychology and not from biology. The theme of this chapter, therefore, is that although psychology cannot be reduced to biology, biology remains

a necessary perspective for a complete understanding of events at the level of psychology.

Although psychology is generally viewed from a natural science perspective (i.e., behavior is as natural a phenomenon as rolling balls down inclined planes was to Galileo), the discipline has few genuine “laws.” Arguably, this is due both to the relative immaturity of the field and to its involvement with misguided intellectual efforts. Scientific progress in psychology has been retarded by frequently being lost and enamored in its own blind alleys of alchemy, phrenology, and atomistic reductionism. Hence, it is worthwhile to heed the admonition of Lerner (2004a) when he suggests, “We are at a point in the science of human development where we must move on to the more arduous task of understanding the integration of biological and contextual influences in terms of the developmental system of which they are a dynamic part” (p. 20).”

Psychology, then, is the unique science of behavior, although greatly influenced by principles of the other sciences. For example, as Medawar (1974) frames it:

Every statement which is true in physics is true also in chemistry and biology and ecology and sociology. Likewise, any statement that is true in biology and “belongs” to biology is true in sociology. Thus a characteristically physical proposition like $E = mc^2$ is true also in all the sciences. More usually, however, a physical or chemical statement such as “the atomic weight of potassium is 39” is simply not interesting in a subject like sociology and does not bear at all upon its distinctive problems. (p. 62)

This same idea was more recently posed by Gilbert and Sarkar (2000), who stated that when examining cells, the spin of a quark is simply not relevant. In addition, “If one asks why peacocks have long tail[s], it will not help to inquire about the physico-chemistry of feathers” (Bauchau, 2006, p. 37). However, the atomic weight of potassium would be relevant to studies in physiological psychology, especially when examining neuronal functioning, just as are principles of physics when studying animal locomotion (Vogel, 1998). Thus, although psychology strives to develop its own unique principles and laws, these will of necessity be compatible and consistent with those of all of the other sciences. For the most part, the properties of the physical world, organized at lower levels of complexity than at least biology, function as background constants for the study of psychology. So, although it is important that the atomic weight of potassium is 39, in so far as this molecular structure affords potassium a role in the action potential of neurons, for pragmatic purposes there is no

point in discussing them as psychological variables, because they do not vary. In contrast, the specific organization and function of the endocrine system across mammalian species does vary, and thus should be considered when defining the psychological capacities or potentials for a given species or individual (see Nesselroade & Molenaar, Chapter 2 of this volume for an extended discussion of the role of variation in psychology).

Presenting psychology as a unique science is, of course, not a new approach. As early as the 1920s, J. R. Kantor (1924, 1926) was making this case and arguing that, although biology is important for psychological events, psychology was not a biological science but was, rather, a psychological science. T. C. Schneirla (1949) later joined in discussing psychology in this way. Contemporary relational developmental systems psychologists have more recently also embraced this understanding of psychology (e.g., Lerner & Overton, 2008).

A RELATIONAL DEVELOPMENTAL SYSTEMS APPROACH

Dynamic systems “theory” (Lewin, 1992; Michel & Moore, 1995) or what in developmental psychology has been termed *relational developmental systems* (Lerner & Overton, 2008) is an organizing metatheory that recognizes the importance of *relations* between events. From this perspective, organisms are not simply collections of organs and other parts; rather, they operate holistically, their parts are interdependent, regulating each other. The importance of this distinction cannot be overstated. Indeed, the modus operandi of psychology is the study of dynamic relations between the multiple elements comprising psychological systems. The philosophical shift in psychological science away from a reductionistic and static orientation aimed at understanding the structural elements of behavior (i.e., psychological causes must be physically located in either a biological, psychological, or sociological entity) toward a dynamic, holistic, and relational orientation extends from metatheory through the articulation of methodologies to the conceptualization of all psychological constructs (Overton, 2006). This was recognized early on by the Nobel Laureate Charles Sherrington (1906/1947, 1951/1964). Furthermore, organisms are not separate from or independent of their environments but are *fused* with them. The environment, thus, is seen to be part of the organismic “whole.” This important way of looking at organisms has a long history in modern psychology (von Bertalanffy, 1933; Kantor, 1959;

Lerner, 1998; Overton, 1975). Our discussion of the relation of biology to behavior is framed in this perspective.

Approaching psychology as a biopsychosocial science resolves the ancient nature–nurture controversy by recognizing that organisms are simultaneously biological and psychological/social beings, and that each of these perspectives plays necessary roles in the origin and maintenance of behaviors. Ingold (2000) put it this way: “We do not progress, in the course of our lives, from a stage of biological incompleteness as ‘mere’ organisms, to one of social completion as fully fledged persons. We are fully and indissolubly organism and person from beginning to end” (p. 285). As Donald Hebb (1953) once remarked, behavior is 100% biology (nature) and 100% psychology (nurture). In a more contemporary formulation of this same idea, Overton (2006) remarked, “The character of any contemporary behavior...is 100% nature because it is 100% nature” (p. 33). Accordingly, following Seay and Gottfried (1978), behavior is understood to be a result of the dynamic interplay of five sets of factors:

1. *Phylogenetic set*—refers to the organism’s evolutionary status, that is, what it is as a species. This is embodied in Kuo’s (1967) “principle of behavioral potentials,” which suggests that each species is endowed with the potential to behave in species-typical ways (Haraway & Maples, 1998). Of course, there is no guarantee that those potentials will be actualized. Thus, as Montagu (1952/1962) points out, “The wonderful thing about a baby...is its promise” (p. 17), suggesting that we are born *Homo sapiens*, but we have to *become* human beings. Another way of saying this is that human nature (or that of any species) is not a direct product of biology, but rather a set of characteristics acquired during the course of growth and development.
2. *Ontogenetic set*—refers to the developmental history of the organism, from the moment of its conception to its death. Included here is biological maturation, the process of bringing the various tissues, organs, and other parts of the organism to full functional development. The probabilistic nature of this ontogeny is underscored. Nothing in development—embryologic or behavioral—is guaranteed by genes; nothing is preformed or preordained (Gottlieb, 1992; Nieuwkoop, Johnen, & Albers, 1985). It is crucial to note that the developmental stage of the organism profoundly impacts its behavior and the way in which it reacts to stimuli.

3. *Experiential set*—the multitude of experiences an organism accrues throughout its life course does much to direct its future development (Lerner & Ross-Bushnagel, 1985). Here, following Schenirila's (1972/1957) definition of experience as "all stimulative effects upon the organism through its life history..." (p. 269), it also refers to all actions initiated by the organism (Overton, 2006). Thus, experience is both what happens to the organism and what it does. Kantor (1959) referred to this experiential history as the "reactional biography." The reactional biography begins at conception and continues to be built up until the organism's death. Every stimulus and each act affects the organism and changes it, though some stimulation and some acts have much more profound and obvious effects than others. Learning, for example, is an important process in behavioral change, but it is nothing more than a special set of experiences.
4. *Cultural set*—refers to the organism's function in environments. The organism-environment forms a functional whole, and consequently, environments are necessary features of the organism's biological and behavioral development. This is most obvious in humans, who have developed contextual cultural systems (e.g., religion, dietary practices, social institutions) that impact in multiple ways on behavioral development. But all living organisms, though perhaps at less complex levels, function within environments of their own making. Different species may inhabit different environments, eat different foods, and so forth. This important point was stressed by the ethologist Jacob von Uexküll (1957), who termed the behavioral environment of an animal its *Umwelt*, its sensory-perceptual world (see also Michel, In press). Chimpanzees, for example, display different behavioral adaptations related to their unique environments (Matsuzawa, 1998). Two communities separated by only 10 km display markedly different behaviors. These differences include nest building, ant dipping, use of leaves for water drinking, food choices, and many others. These differences are less complex cultural traditions than are found in more complex species.
5. *Individual set*—refers to the uniqueness of each individual organism and how that uniqueness relates to its development. One animal may be more or less sensitive to sounds, or may have a developmental abnormality that limits its interactions with its world,

or may be larger or smaller than its conspecifics, and so forth. This set of factors recognizes the contribution of the individual's unique genotype and how that, in dynamic interaction with contextual influences, may render it a different behaving creature than all others.

These five organizational sets provide the ontological structure of psychology. The common theme that runs through all of these organizational sets is that temporal processes and relational constructs are the central conceptual features of each set. The challenge for the study of psychology is to account for these dynamic relational processes that occur at multiple spatial and temporal streams, becoming manifest in the nexus of the individual organism.

BIOLOGICAL FACTORS IN BEHAVIORAL DEVELOPMENT: EVOLUTION AND GENETICS

We turn now to a discussion of the several aspects of biology that play a role in the genesis of behavior and development. It should again be emphasized at the outset of this discussion that the position taken here is that biology plays an important, but not foundational, role in behavior and development. The impact of biology in psychological phenomena is relatively recent, it being the case that "Biology as a unified science did not exist until well into the 20th century" (Smith, 2008, p. x).

Evolution

Evolution is an appropriate starting point for an enquiry into the relation of biology and psychology because, in a sense, everything in life can be said to begin here. Science speaks of cosmic evolution, the universe originating with the Big Bang (Singh, 2005), though, of course, the principles and mechanisms of cosmic evolution are different from those of biological evolution (Darwin, 1859). One corollary of cosmic evolution is that given enough time, hydrogen and helium become living organisms (and eventually sentient beings)—it is at this point that biological evolution and natural selection emerge and become possible (Weber, 2007). Biological evolution can be described as change in the characteristics of populations of organisms over time. The concept applies only to groups (species) and not to individuals; individuals develop over time but do not themselves evolve. Evolutionary changes are inherited, biologically and culturally, in the sense of being

passed down across generations. Of course, as Reid (2007) has pointed out, the path to sentience is not inevitable, merely a result of emergent evolution:

Thus, mind, as a manifestation of those novel internal relations, becomes a likely outcome at the higher levels. But it is not predetermined by the early generative conditions. And it certainly does not reside hylozoically in the Big Bang nor in the simplicities of solid-state physics... An expanding universe has the potential to develop carbon etc. Carbon etc. have the potential to originate life, Life has the potential to complexify through reproduction...and it is as a *result* of biological evolution that energy flow increases in the biosphere. (pp. 428–429)

It is instructive to begin our discussion of evolution with a quotation from Ernst Mayr, one of the 20th century's leading evolutionary biologists:

The most consequential change in man's view of the world, of living nature and of himself came with the introduction over a period of some 100 years beginning only in the 18th century, of the idea of change itself, of change over long periods of time: in a word, of evolution. Man's world view today is dominated by the knowledge that the universe, the stars, the earth and all living things have evolved through a long history that was not foreordained or programmed, a history of continual, gradual change shaped by more or less directional processes consistent with the laws of physics. (1979, p. 47)

The modern theory of evolution dates from a joint presentation on behalf of Charles Darwin and Alfred Wallace to the Linnean Society of London in 1856. Of course, Darwin and not Wallace is remembered as the founder of modern evolution ideas because of the weight of the evidence he collected and presented in his 1859 discourse, *The Origin of Species*. One of the basic ideas of evolution, that present forms of plant and animal life have changed over vast periods to become as they now are, is at least as old as the Greek philosopher Anaximander, who believed that all life began in the sea and gradually evolved to take advantage of land and ocean environments (Futuyma, 1998). What was missing in older ideas of evolution was a mechanism or guiding principle by which evolution would be given order and direction. That principle was supplied by the idea of natural selection and later by the ideas of genetics.

It is well known that Darwin formed his idea of natural selection after a mapping expedition over much of the world with the British Navy in the late 1830s. He noted the wide variety of animals and how their variations were

related to their unique environments. His observations lay dormant, incubating several years while he experimented with breeding and cross-breeding animals and plants. The key idea of Darwin's theory, which distinguished it from earlier evolution ideas, was that of natural selection. All species and all individuals must survive a natural selection. Here was a principle to give guidance and direction to the process of evolution. Evolution must flow always in the direction of functional effectiveness, in the direction of survivability.

Darwin had formed the basic ideas of his theory of evolution by the end of the 1830s, but came forth to publish those ideas only when Wallace independently conceived his own similar ideas in the mid-1850s. Following the joint publication with Wallace in 1856, Darwin made use of his 20-year head start in working with his own theory of evolution. In 1859 he published his basic book on the subject. *The Origin of Species* became an international sensation, and the theory of evolution soon became known as "Darwin's Theory." It has become one of the most influential ideas in the history of thought. Mayr (1979) has said that the synthetic theory of evolution is "*the* organizing principle of biology" (p. 47, emphasis added). Dobzhansky (1973), another important contributor to the development of modern evolutionary theory, titled an article, "Nothing in Biology Makes Sense Except in the Light of Evolution." Indeed, our understanding of life, the world we stand upon, and the universe which surrounds us is an evolutionary understanding.

As with all major scientific theories, Darwinism is an exemplar of simplicity. It can be summarized in three fundamental principles: (1) Species produce many more eggs and offspring than can survive and reproduce themselves; (2) sexual reproduction permits a wide variety of genetically different offspring to be produced by each breeding pair, male and female; (3) from among this variability, nature selects individuals whose characteristics result in survival and breeding capability. Note that these principles hold for all organisms, animals as well as plants. Because species evolution results from differing rates of survival and reproduction among various types, the relative frequencies of the types change over time. In this sense, then, evolution can be seen to be a sorting process (Griffiths et al., 2005).

Darwin knew that characteristics that permit the organisms possessing them to survive were likely to be passed on through the successful reproduction of those organisms. He knew nothing, however, about the mechanism of such inheritance. Our current understanding of genetics, which began with the work of the monk Gregor Mendel, provides

this mechanism. The canonical theory of evolution, referred to as “The Modern Synthesis,” combines Darwin’s ideas of natural selection and Mendel’s ideas of genetics (e.g., Mayr & Provine, 1980).

Theories in science are of necessity dynamic. All the facts are never fully collected; that is why science is characterized as a self-correcting discipline. New discoveries and new facts rarely result in the discarding of a strong theory; rather, the course taken is to tweak the theory to accommodate the new findings. So it is with Darwinism. Although Darwin provided the fundamental law of his theory, that of Natural Selection, Saunders and Ho (1976, 1981) suggested that an increase in complexity over geologic time (i.e., with evolution) can be understood as a second law of Darwinism. We have discussed complexity theory and its corresponding idea of emergence fully in other publications (Greenberg, Partridge, & Ablah, 2007; Partridge & Greenberg, in press). It is sufficient here to state that increases in complexity and the epigenetic emergence of novelty are the rule in evolution. This should come as no surprise, for as many, including Stephen J. Gould (1997b; see also Krasny, 1997), Maynard Smith (1970), Sean Carroll (2001), and others, have pointed out, when you begin with a single cell, with simplicity, there is only one direction to go in and that is up toward greater complexity. Maynard Smith (1970) explains, “It is in some sense true that evolution has led from the simple to the complex: prokaryotes precede eukaryotes, single-celled precede many-celled organisms, taxes and kineses precede complex instinctive or learnt acts...And if the first organisms were simple, evolutionary change could only be in the direction of complexity” (p. 271).

It is in this context that the important evolutionary concept of anagenesis becomes significant. Anagenesis is a concept that implies evolutionary progress (Aronson, 1984; Greenberg, 1995; Overton, 1975; Yarczower, 1984): “The cardinal defining features of behavioral and psychological anagenesis [are] increases in ontogenetic plasticity and improvements in behavioral versatility, the latter through enhanced perceptual, cognitive, learning, social, and/or motor skills” (Gottlieb, 1984, p. 454). The progress referred to here is evolutionary change. Although “progress” is often a highly charged and controversial idea in evolutionary thinking, misunderstandings are avoided by adopting Stephen Jay Gould’s (1988) argument that “we can preserve the deep (and essential) theme of direction in history, while abandoning the intractable notion of progress” (p. 321). The fossil record presents virtually undeniable evidence that organismic complexity has increased

with time. Stated differently, with few exceptions, more recently evolved forms are more complex in their behavior than are earlier evolved forms. As evolution has continued, it has preserved many simple forms, perhaps unchanged over millennia, but the new forms produced have tended strongly in the direction of increasing complexity. Chaisson (2001) has thoroughly discussed the idea of complexity in nature. With respect to the application of complexity to development in psychology, the following statement by Arthur (1993) is telling: “The writer Peter Matthiessen once said, ‘The secret of well-being is simplicity.’ True. Yet the secret of evolution is the continual emergence of complexity. Simplicity brings a sparseness, a grit; it cuts the fat. Yet complexity makes organisms like us possible in the first place” (p. 144).

The issue here is not only controversial, it is contentious, with debate frequently occurring from ideologic perspectives (Lewin, 1992). However, in the context of the argument presented in this chapter, Bonner’s (1988) position is persuasive:

There is an interesting blind spot among biologists. While we readily admit that the first organisms were bacteria-like and that the most complex organism of all is our kind, it is considered bad form to take this as any kind of progression... It is quite permissible for the paleontologist to refer to strata as upper and lower, for they are literally above and below each other...But these fossil organisms in the lower strata will, in general, be more primitive in structure as well as belong to a fauna and flora of earlier times, so in this sense “lower” and “higher” are quite acceptable terms...But one is flirting with sin if one says a worm is a lower animal and a vertebrate a higher animal, even though their fossil origins will be found in lower and higher strata. (pp. 5–6)

Reid (2007) offers a simpler way of saying the same thing: “To say that human is higher does not disparage the worm, but implies that perfection-of-adaptation-to-environment is a totally inadequate assessment” (pp. 432–433). Bonner’s (1988) book is an exposition on the evolution of biological complexity, a phenomenon he likens to a “law” of evolution. That this trend toward complexity in evolution is so pervasive and agreed on has led some to identify it as “The Arrow-of-Complexity hypothesis” (Miconi, 2008).

The idea of evolutionary progress has been troublesome to scientists since Darwin’s time (Nitecki, 1988). The problem lies in finding a reasonable and objective basis on which to judge one species as representing an improvement,

or an advance, over another. Progressive change may be identified as a sustained or continuing change in any particular direction. Maier and Schneirla (1935/1964) found it useful to equate evolutionary progress with increases in behavioral complexity and plasticity as one ascends through a hierarchy of behavioral levels of organization. Associated with that hierarchy are increases in nervous system complexity, organization, and integrative functions (Bonner, 1988; Jerison, 1994). The idea of complexity is no longer the poorly defined construct it once was. By wide agreement (e.g., Carroll, 2001), complexity in biological systems can be assessed by the number of different components—cell types, structures, even gene number—possessed by organisms. As pointed out earlier, Saunders and Ho (1976, 1981) have gone so far as to identify a positive relation between progressive complexity and evolutionary advancement as a second law of evolution, together with natural selection. Increasing complexity is closely related to improved organization and increased plasticity of behavior, which accompany evolutionary elaboration of the nervous system. Indeed, as Chaisson (2001) has pointed out, “Whatever measure of complexity is used, it is hard to avoid the notion that “things”—whether galactic clouds, slimy invertebrates, luxury automobiles, or the whole universe itself—have generally become more complicated throughout the course of history” (p. 7).

A cornerstone of Darwinian theory is that evolutionary change is slow and gradual, taking millions of years. The absence of a corresponding fossil record is one source of challenge to this idea. However, Eldredge and Gould (1972) provided an explanation for these gaps in the fossil record and at the same time demonstrated the dynamism of Darwinian theory—that it can be tweaked. Their idea is referred to as *punctuated equilibrium*. The proposal, now widely accepted as another modification of Darwinian theory (Gould & Eldredge, 1993), is that species remain unchanged for long periods (i.e., in equilibrium), and that these long periods of no change are punctuated by episodes of relatively rapid (e.g., in geologic time, tens or hundreds of thousands of years) change. Thus, there is no gradual fossil record to be discovered. This is saltatory, rather than gradual, evolution and is an example of how the principle of emergence plays a role in our contemporary understanding of evolution (Reid, 2007). (See MacWhinney, Chapter 14 of this volume, for an extended discussion of emergence in human language development.)

We entered the 21st century on the heels of two expensive and popular scientific efforts, the Decade of the Brain

(<http://www.loc.gov/loc/brain>) and the Human Genome Project (http://www.ornl.gov/sci/techresources/Human_Genome/home.shtml). Both purported to put to rest the search for the origins of behavior. The former endeavor sought to put the entire burden of behavior on the brain, the latter on the human genome. Both, of course, celebrated the nature side of the nature–nurture equation and, importantly, both failed to “take development seriously” (Robert, 2004). This has changed with the most recent modification of Darwinism in its rerecognition of the significance of development in the evolutionary process. This takes the form of a newly developed area of study, evolutionary developmental biology or evo-devo. In the 20th century, the study of embryology and genetics took different paths, the two failing to acknowledge the importance of each for the other. This “was a conceptual block that continued to be an issue among biologists until the 1980s and 1990s, when the application of molecular genetics to development promised to bring the two fields [i.e., genetics and embryology] back together in the new disciplinary synthesis of ‘evo-devo’” (Allen, 2007, p. 151).

Evo-devo entails, among other things, a new understanding of genetic functioning and the role of development in this functioning. And with the introduction of evo-devo, there has been a reemergence of the centrality of concept of epigenesis (i.e., increasing system complexity and the *emergence* of irreducible *novel* systems properties and competencies occurring through biological–environmental interactions). The novelty of this newly emerging discipline has been summarized as follows by Jason Robert (2004), a philosopher (of biology) who has argued forcefully for the return of development in the understanding of modern approaches to biology in general and evolution in particular:

Despite differences in approach, evo-devoists tend to hold to a core of theoretical presuppositions, including: (a) the hierarchical nature of development and evolution; (b) the need to focus on developmental processes—interactions—between genotype and developing phenotype; and (c) the belief that analysing developmental processes and mechanisms, and their evolution, improves our understanding of both evolution and development. Studying development in evolutionary context, and evolution in developmental context, increases the explanatory scope of both sciences. (p. 97)

Before the Human Genome Project, it was believed that the human genome contained about 100,000 genes. We now know that number to a somewhat more modest figure of

20,000 to 30,000, no more really than the common house mouse. It is also known that the genomes of *Homo sapiens* and our closest relative, the chimpanzee, are some 98.7% identical. The question thus arises, if the genomes of so disparate animals are so similar, what accounts for the vast differences in the phenotypes between these organisms?

The answer lies not in the genes themselves but in the arrangement of these genes on chromosomes. To be more precise, “It is not so much mutational events and new genes that are the origin of complex novel structures, but rather developmental reorganization and the cooptation of established regulatory pathways into new developmental functions” (Miller, 2007). As Evelyn Fox Keller (2002) describes, the spatial position of genes plays a major role in their expression; context, then, is key, and positional information and the central dogma (which is discussed later in this chapter) are now understood to be “the two theoretical cornerstones of molecular developmental biology (the other being the central dogma)” (p. 180). Genes, then—and this is a major point of the evo-devo movement—do not exist in a vacuum; rather, they function in a cell with many components and other genes, the myriad contents of which interact and play a role in the turning on and off of different genes. It is safe to agree with the philosopher of biology, Michael Ruse (2006), that the development of evo-devo has opened the way to some of the most interesting discoveries in molecular biology, not the least of which are the “amazing homologies between humans and fruitflies for starters” (p. 36). It is of interest to note that some of these ideas have been known for a long time, though they did not make their way into the popular literature until more recently. For example, as early as 1972, Hull wrote: “As it turns out, the same gene frequently functions differently, depending on its position on the chromosome, a phenomenon known as the position effect” (p. 498). It is now recognized that this, and other cellular environmental influences and developmental processes, have profound effects on genetic expression. Some genes are not even found in the embryo (e.g., those for B- and T- cell antigen receptors) but are constructed during development (Gilbert & Sarkar, 2000).

Problems of Evolutionary Psychology

The perspective of atomistic reductionism has been the cornerstone of the relatively new field of Evolutionary Psychology, which presents a genocentric explanation of human behavior. The basic argument here has been that the genome has been fixed since the days of our hunter-gatherer ancestors, and all behavior is accounted for by random

genetic variation and natural selection. The alternative to this perspective is the holistic relational position that, although evolution, like genes, represents partial processes in the nature and development of behavior, there is ample evidence that evolution has continued across history, and factors are at work beyond variation and selection.

This alternative position has been expressed by Lickliter and Honeycutt (2003), among others (e.g., Blumberg, 2005; Kaplan & Rogers, 2003), in their critique of atomistic reductionistic application of evolution to psychology and development. Although evolutionary psychology posits a universal human nature, Ingold (2000) discusses the crucial role of culture in making us all different, identical twins included! Here the first important point to be made is that many evolutionary forces have been at work since the appearance of our species in the Pleistocene. It is an error to suggest that our behavior as *Homo sapiens* is the result of our adaptation to Pleistocene events, as evolutionary psychologists not only imply but explicitly state (e.g., Buss, 1999, 2005; Pinker, 2002). For evolutionary psychologists, adaptation to Pleistocene events is perhaps the fundamental principle involved in behavioral evolution. However, as Buller (2005) stresses, “There is ongoing evolution in human psychological adaptations, so it is mistaken to believe that our minds are adapted to our Pleistocene past” (p. 13). Indeed, as Ingold (2000) points out, nothing has been transmitted to us by our Pleistocene ancestors, “For the growth of practical knowledge in the life history of a person is a result not of information transmission but of guided rediscovery” (p. 288).

Rejection of the atomistic reductionistic approach also entails a rejection of the adaptationist agenda of evolutionary psychology. As many have pointed out, including such notable evolution scientists as Gould (1997a), even Darwin suggested that mechanisms other than adaptation are at work in evolution. It is a mistake and a misunderstanding of Darwinism to suppose that there is anything approaching the consensus claimed by evolutionary psychologists. Rather, pluralism of mechanisms is the rule in the still developing paradigm of evolution. For example, we now understand evolution to involve punctuated equilibrium, genetic drift, mutation, and other processes, as well as natural selection. In fact, evolution does not always involve changes in the genome. It is now recognized that not all genes of the human genome get expressed. Evolution can occur if different portions of the genome are expressed, the result perhaps of environmental impact. This would result in new phenotypes (see Honeycutt, 2006).

Some have also argued that “evolutionary psychology has recently gone too far in its epistemological agenda, as it attempts to uncover the brain ‘mechanisms’ that constitute ‘human nature’” (Panskepp & Panskepp, 2000, p. 108). The holistic relational alternative to this notion of innate and universal human nature is found in Montagu’s position that we are born *Homo sapiens*, but we become human beings. This too was the point of Kuo (1967), who raised the issue of whether a cat was a rat killer or a rat lover, and *empirically* answered the question in this way: Kittens raised with rats out of sight of cats which kill and eat rats, never kill rats themselves, even when hungry. Never having seen a rat killed or eaten, it is simply not a food object for them. Animal nature is a result not of biology alone, but of developmental history. Behavior, thus, even human behavior, is enormously plastic (Lerner, 1984). Herein lies the significance of relational developmental systems theory for psychology and especially for developmental psychology.

Another related serious difficulty with contemporary evolutionary psychology is its genocentric arguments from animal to human behavior. Of course, it is almost universally accepted now in psychology that there is continuity in behavioral processes from animals to humans. This is reflected in current research in cognition, studies of the origins of language, the fundamental workings of learning, and so forth. Animal models can be extremely useful in this regard, in the search for the evolutionary origins of much of human behavior. Strains of mice and the fruit fly, for example, have been the workhorses of behavior geneticists for 50 years or more. But such models have their limitations; the social climate, empowered by the enormous success of the Human Genome Project, one of the most costly scientific endeavors in history, has fostered an almost frenzied search for the “gay gene” and the “schizophrenia gene.” Nevertheless, “There is so far only one known example of male to male matings being switched on by one gene. This is the fruit fly...[However] one would be hard pressed to call a fruit fly homosexual” (Kaplan & Rogers, 2003 p. 223). Lewontin’s (1997, p. 29) comment is germane in this context:

The concentration on the genes implicated in cancer is only a special case of a general genomania that surfaces in the form of weekly announcements in *The New York Times* of the location of yet another gene for another disease. The revealing rhetoric of this publicity is always the same; only the blanks need to be filled in: “It was announced today by scientists at [Harvard, Vanderbilt, Stanford] Medical

School that a gene responsible for [some, many, a common form of] [schizophrenia, Alzheimer’s, arteriosclerosis, prostate cancer] has been located and its DNA sequence determined. This exciting research, say scientists, is the first step in what may eventually turn out to be a possible cure for this disease.

Unfortunately, there is rarely a follow-up announcement that the findings were in error or have failed to be replicated! One of the best recent discussions of this issue is found in Joseph (in press). A good example concerns the ongoing search for the gene(s) for depression. There have been many reports of finding them, but a new meta-analysis of 14 studies before 2008 revealed *no* evidence of a relation between genes and the risk for depression (Risch et al., 2009). Of course, genetics is involved in depression, this report indicates, but as a fusion with experience. The behavioral sciences in general and evolutionary psychology in particular have tended to ignore or perhaps are not even aware of contemporary empirical findings in molecular biology, evolutionary biology, and genetics, a point emphasized by others (e.g., Gottlieb 2004; Kaplan & Rogers, 2003; Lickliter & Honeycutt, 2003). As Lewontin (1997) has remarked, “Even individual scientists are ignorant about most of the body of scientific knowledge” (p. 28). Thus, it is now known that genes are not directly responsible for phenotypic expression, but rather, the environmental context of development plays a crucial role in this process; that genes not only work from the inside out, but that behavior, too, can influence the expression of genes (referred to as “downward causation” by Campbell, 1990); that not all genes of a genome get expressed; that natural selection is but one of several mechanisms responsible for evolutionary change; and that the path from genes to physical or behavioral traits is enormously complex and indirect. It is now recognized that social behavior itself can turn genes on and off (Robinson, Fernald, & Clayton, 2008). Thus, foraging by honeybees occurs as a result of the effect of colony pheromones that alter the expression of hundreds of genes in the bee brain. In the swordfish, some genes are turned on as the female swordfish interacts with some male swordfish and off when the interaction is with other female swordfish. Genomes remain active throughout life to many environmental stimuli including those from the social context. Some of these social signals have epigenetic effects that are inheritable, but not through changes in the DNA sequence—transgenerational inheritance via epigenetic pathways (Harper, in press). That social behavior has been shown to affect brain genetics, which affects neuronal activity, provides a bidirectional

pathway from altered brains to altered behavior. This work calls to mind the discussion of social effects on brain disorders, labeled sociogenic brain damage (Montagu, 1972). Social deprivation, economics, and malnutrition all have dramatic effects on brain development. Indeed, we have known for some time that social conditions have a profound effect not only on brain development, but on physical development in general, a phenomenon labeled *psychosocial dwarfism* (Reinhart & Drash, 1969). It is also the case that drug addictions may be related to drug-induced changes in gene expression in key brain reward areas (Renthal & Nestler, 2008). Work of this nature suggests that we still have a great deal to learn about the nature and role of the gene in the overall developmental system.

Another idea at the center of the evolutionary psychology program is that the human mind is constructed of innate, domain-specific cognitive modules, evolutionary adaptive holdovers from the Pleistocene (Pinker, 2002). (See discussions by Buller [2005], Kaplan and Rogers [2003, and Uttal [2001] on mental modules.) Mental modules constitute a rather vague concept, and information is seldom provided concerning their specific nature or numbers (though some have speculated that the number might be in the “hundreds or thousands” [Toobey & Cosmides, 1995, p. xiii].) As Panskepp and Panskepp (2000) argue, we too “believe that some currently fashionable versions of evolutionary psychology are treading rather close to neurologically implausible views of the human mind... there is no [convincing] evidence in support of highly resolved genetically dictated adaptations that produce socio-emotional cognitive strategies within the circuitry of the human neocortex” (p. 111).

Other critical features of the biological sciences are misunderstood or ignored, or both, by evolutionary psychologists. A common response by evolutionary psychologists to such criticism has been that it is they who are misunderstood, and that they do not suggest that behavior is genetically determined or innate. However, and unfortunately, these responses amount to little more than lip service, as reference to a recently established Web site illustrates (University of Sheffield, n.d.). This is the Web site of a group known as *The AHRB Project on Innateness and the Structure of the Mind*, the members of which are a veritable Who’s Who of the evolutionary psychology elite. In their own words, from their Web site: “The project brought together top scholars in a broad range of disciplines—including animal psychology, anthropology, cognitive psychology, developmental psychology, economics, linguistics and psycholinguistics, neuroscience,

and philosophy—to investigate the current status and most promising future directions of nativist research.”

Evolution and Behavior

An organism’s status as a species endows it with the potentials to behave in ways unique to that species. This idea is captured by Kuo’s (1967) “principle of behavioral potentials,” which asserts that each species is endowed with the potential to behave in species-typical ways. The same idea is the basic assumption of contemporary work on “embodiment” (see Overton, Mueller, & Newman, 2007), embodiment being the claim that perception, thinking, feelings, and desires are contextualized by our being *active agents* with this particular kind of body. A concrete illustration of these concepts is found in the song “Can’t Help Lovin’ Dat Man” from the musical *Show Boat*: “Fish gotta swim, birds gotta fly.” Of course, there is no guarantee that potentials are actualized. This is why the notable evolutionary biologist Paul Ehrlich suggested that we are better off thinking of human (or species) natures in the plural, rather than a single nature (Ehrlich, 2000).

As species evolve, their behavioral potentials change. In fact, there is a close tie between behavior and evolution. Surprisingly, the relation goes not from evolution to behavior, but from behavior to evolution. In an important and real sense, it is what an organism does that allows it to survive and pass on its genes to future generations. Said another way, it is the phenotype, in this case, the animal’s behavior, and not the genotype that drives evolution. The Nobel biologist Waddington (1969) stated:

Now natural selection obviously acts on the phenotype. If for instance, natural selection demands that a horse can run fast enough to escape from a predatory wolf, what matters is not what genes the horse has got, but how fast it can run. It is irrelevant whether it can run fast because it has been trained by a good race horse trainer, or because it has got a nice lot of genes. (p. 360)

Ernest Mayr (1985) pointed out that, in addition to being adaptive, behavior serves as a pacemaker in evolution, “by leading organisms into new niches or environments which exert a new set of selection pressures and thus may lead to major evolutionary changes” (pp. 59–60). As an example, consider the following: For almost 50 years, Japanese primatologists (Nishida, 1986) have been studying the social behavior and emergent traditions of Japanese macaque monkeys. Provisioned with novel foods—potatoes and rice—the monkeys soon began to toss handfuls of rice gathered from the sandy beach into the water, where the

rice would float and the sand would sink. The monkeys thus discovered a way to wash sand from their food. These practices spread throughout the colony and are now part of the animals' normal behavioral repertoire. The practice is handed down from generation to generation—a primitive form of cultural transmission, though alternative explanations of this behavior have been proposed (Heyes, 1998). Once they began spending more time near and in the water, young macaques began playing in it. This play led to the development of new behavioral skills, such as swimming. The animals also incorporated new foods into their diets, fish, for example, and may now be capable of swimming to distant islands. Behavior such as this would subject them to new ecologic pressures and potentially affect the course of their evolution—a form of “Darwin’s finches” scenario. This is an example of how behavior may drive evolution. Of course, as organisms change over time and new species evolve, the new biologies of these species endow them with new behavioral potentials. In this way, we see that evolution affects behavior as well.

Genetics—The Mechanism of Evolution?

When Darwin first put forth his theory of evolution by natural selection, he knew that traits were passed on from one generation to the next, but he knew nothing of how that was accomplished. It was only in the early part of this century that a group of biologists, including Ernst Mayr, Theodosius Dobzhansky, and George Gaylord Simpson, incorporated the Mendelian system of genetics into evolutionary theory. The result produced what is now referred to as the Modern Synthesis, or the Synthetic Theory of Evolution, or “neo-Darwinism,” a synthesis of natural selection and genetics (Futuyma, 1998).

Evolution is now understood to involve the formation of new species by changes in the gene pool that characterizes a parent species (Mayr, 1970). These changes arise in several ways, most dramatically when a natural barrier arises and separates groups of animals. The flow of genes between them is halted and each species, or isolated gene pool, now becomes subject to different ecological pressures. Because the flow of genes is the result of reproduction, the successful attracting of mates becomes a crucial event in evolution. This is accomplished by behavioral means—bird song, courtship displays, flash rates by fireflies. Again, we see the important links between behavior and evolution.

What is a gene? “It is almost common knowledge among biologists and philosophers of biology...that the classical molecular gene concept is not sufficient any longer in the

face of the complex interactive processes being reported by molecular biology” (Neumann-Held, 2001, p. 69). Neumann-Held and others (e.g., Keller, 2000, 2002; Moss, 2003) also point out that since the end of the 20th century, the very notion of just what a gene is has changed. It is no longer sufficient to speak of “the” gene; the term has come to mean different things to different people. The term *gene* is now understood to be shorthand for several different kinds of units. It may be that “gene” is not so much an identifiable *thing* as it is a *process* involved in binding DNA to other factors that act together in polypeptide production. At its inception, and indeed until only very recently, the gene, seemingly so concrete and definitive a structure, was nothing more than a hypothetical construct in a statistical equation (Burian, 1985; Keller 2002). Even with the discovery of the unique and highly functional structure of deoxyribonucleic acid (DNA) by Watson and Crick (1953), little more empirical light was shown on the subject than simply having a molecule with the kinds of properties through which the hypothetical gene might work.

However, it is now understood that there is no explanation in attributing a trait, behavioral or structural, to genetics in light of what converging current research from several disciplines indicates (Moss, 2003). Many behavioral scientists, behavior geneticists, and evolutionary psychologists seem to be unaware of these recent developments in our understanding of genetics, as Gottlieb (1998, 2004) and others (e.g., Lickliter & Honeycutt, 2003) have pointed out. It turns out that there is no information in the genome to be triggered or nurtured by the environment, though this is the current consensus in the behavioral and much of the biological sciences. This has been consistently and reliably demonstrated empirically in data from a large number of studies, which give us a new picture of the role of genes in development in general. “For instance, genes are not informational in the way supposed, nor do they initiate or direct ontogeny, there is no such thing as a genetic programme, and there is no straightforward ‘unfolding’ relation from genotype to phenotype” (Robert, 2004, p. 39). This type of information is only recently making its way into the popular press (e.g., Angier, 2008), where it is likely to have a greater impact in educating the public than do scientific publications. Our own students, for example, reluctantly accept what we have to say about such things but readily believe in what they read in *Time* magazine or hear on the nightly news!

It is now known that genes do little more than code for the many different proteins that go into making up living things; the proteins are themselves incorporated into the

ever-changing molecular and cellular structure and physiology that is an individual organism. One way of looking at an organism is as a chemical soup. The biologist Garrett Hardin (1956) said that humans and other animals are not so much *things* as they are *places* where very interesting things are occurring. From this view, the DNA part of this chemical soup sees that certain chemical reactions take place at certain times. Genes participate in turning reactions on or off; they function as catalysts. Similarly, they really operate by participating in the timing of important chemical events. When the default schedule is followed, certain interactions inevitably occur. “There is no need for genes to encode and control those interactions directly. Instead, they follow from the laws of physics, geometry, topology—laws of great generality” (Elman et al., 1996, pp. 41–42).

In this context, it is useful to recall the distinction between the genotype and the phenotype. The genotype is the actual genetic code, the genetic blueprint that influences every cell of our bodies. Because all cells trace their beginnings to a single daughter cell, the genotypes of each cell must be identical. The result of how those genes express themselves is the phenotype, but there is no direct relation here. It is not the case that the genotype codes for the phenotype. Although all cells have the same genotype, some become bone cells, some blood cells, some skin cells. Human beings possess some 256 different types of cells. These different cells arise as a result of epigenetic forces acting on the genes to cause them to express themselves in different ways (e.g., “Cellular differentiation is a classic example where epigenetic phenomena have a critical role” [Renthal & Nestler, 2008, p. 341]). Genes express themselves in the context of a field of internal and external forces that impinge on them (Stoltenberg & Hirsch, 1998). It is known that, in addition to a cell’s own internal chemistry, genes can be switched on and off by signals from other cells and from other aspects of the environment (Gear & Wiles, 2005), including positional information referred to earlier in this chapter. “The path linking genes or molecules to the expression of behavior is long and complex...There are innumerable ways genes can influence development, physiology and the nervous system to affect behavior. Further, the genome has a dynamic relation with behavior, and each influences the other through complex regulatory mechanisms” (Barron & Robinson, 2008, p. 257). The relation between genetics and behavioral phenotypes is extremely indirect. Thus, two strains of inbred mice, C57BL10J and A/J, differ substantially in their aggressive behaviors, not a result of their inheriting

aggressive or nonaggressive genes, but rather the result of their sensitivity to stimulation, a biological factor that is, indeed, an inherited trait, much as myopia is in human beings (Greenberg, 1972). The title of a review of T. C. Schneirla’s writings reflected this: “A Long Way from Genes to Behavior...” (Jaynes, 1973).

Molecular biology has learned a great deal about the functioning of genes in the past few decades, exploding a number of ideas we now see to be myths. These include the notion that single genes affect single traits—eye color, for example. Although some single gene/single traits are known to exist, the common mode is for genes to act in concert with others. What a gene does, then, is very much influenced by which other genes are being turned on or off at any particular time during development. In other words, genes do their work together with other genes, rather than individually. The developmental process, therefore, is not a predetermined one, but rather a probabilistic one. Put another way, “Since it has become evident that genes interact with their environment at all levels, including the molecular, there is virtually no interesting aspect of development that is strictly ‘genetic,’ at least in the sense that it is exclusively a product of information contained within the genes” (Elman et al., 1996, p. 21).

These ideas are in conflict with what came to be known as the central dogma of molecular biology (Crick, 1970), which states that genetic information flows in one direction only—from inside to out, from the genotype to the phenotype. Many have convincingly shown this to be false, most significantly for psychologists such as Gilbert Gottlieb, whose entire body of work showed empirically that structure–function relations were bidirectional (e.g., 2004). Gottlieb (2001) has suggested that few psychologists, and, in fact, many biologists, are simply unaware of recent developments in molecular biology that render no longer valid the standard program of genetics as an unfolding of a set genetic code: “While this fact is not well known in the social and behavioral sciences, it is surprising to find that it is also not widely appreciated in biology proper...[!]” (p. 47). He was not alone in this assessment, as even a molecular biologist has noted (Strohman, 1997). Within this assumptive framework, gene theory derived its key principles (Gottlieb, 2006):

1. Genes must be discrete causal agents “located” in the germ cells. This principle is derived entirely from the Newtonian assumptions of linear, singular, additive, and deterministic causes. Indeed, it was completely assumed as an a priori “given.” The only empirical

observations related to this principle were the basic, observable aspects of sexual reproduction.

2. Genes behaved statistically “as if” they contained independent and unique causal information, which additively combine to form the adult organism, although there were no formal tests of this assumption. The logic was: If our atomistic and additive conceptualization is true, then the statistical properties of the organism would follow certain parameters. The statistical properties follow these parameters; therefore, our conceptualization of the gene is true. Philosophers of science refer to this logical fallacy as “affirming the consequent.”
3. Because traits are predictable from the statistical estimations of Mendel and then later Fisher, both of whom did not include terms representing either development or environmental variation, it was further asserted that the causal information contained in genes was effectively isolated and independent of external influence (either biological or ecological).

BIOLOGICAL FACTORS IN BEHAVIORAL DEVELOPMENT: THE BRAIN AND NERVOUS SYSTEM

We begin our discussion of the role of the brain and nervous system in behavior with a quote from an introductory physiological psychology textbook (Plotnik & Mollenauer, 1978). Although the book was published in 1978, this statement reflects the still prevalent neurologic reductionistic materialism of contemporary psychology. Indeed, it reflects an important goal of the recently completed Decade of the Brain, an international research effort geared to resolving much of our still poor understanding of the functioning of the brain.

If your brain were removed and another put into your skull, who would you be? Your friends would recognize your face but you would not recognize your friends or know their names. You would not know where you lived or who your parents were. You would not joke like or think like or dream like the original you. You would be a different you since the original you was stored in the brain that was removed. With a new brain you would have a different mind and personality even though your original body remained (Plotnik & Mollenauer, 1978, p. 10).

This is incredibly fanciful stuff, especially for a textbook! Of course, it is entirely speculative because

such a procedure has never been performed even with the simplest of organisms. It does, however, reflect the still widely accepted idea that you are your brain, in the same sense that genetic reductionism holds that you are your genome. In more contemporary terms, this is often referred to as the “brain in a vat” theory.

Of course, just as we are more than the sum our genes (Kaye, 1992), we are much more than merely our brains and nervous systems. Again, the notion of embodiment is central here. The Noble laureate Sir Charles Sherrington put it this way, “A healthy man is a set of organs of interlocking action regulating each other, the whole making a self-regulating system” (1951, p. 163). The human being is a highly complex organism, actually a self-organizing and self-regulating system of interrelated and interdependent parts, all of which regulate each other, no one system more crucial to one’s survival than all of the others. An organism cannot survive, or behave, without its heart or liver or lungs, and so forth, or without its nervous system. Although the nervous system links all of the other systems together, it is inaccurate to say that it is more important than any of the other systems, because the very life of the organism depends on the interdependent functioning of *all* of its biological systems as they function in the world. Although it has become habitual to say that the brain does various things such as think and remember, the fact is that it is the *person* who does these things, not his or her brain (Bennett & Hacker, 2003).

Unfortunately, the history of science is riddled with master-organ scenarios. In ancient Egypt, the heart ruled; the early Chinese looked to the liver, heart, lungs, and kidneys in trying to understand the emotions, until, as Critchley (1969) has pointed out, the history of neurology shows that the cerebralists gradually attained increasing acceptance. An excellent recent history of neuroscience (Zimmer, 2004) demonstrates:

More than any other individual, Thomas Willis ushered in the Neurocentric Age...In redefining the brain, Willis redefined the soul as well. It was banished from the liver and the heart, restricted now to the brain and nerves...Willis’s doctrines of the brain and the soul became part of the bedrock of Western thought, and they still lurk beneath many of our beliefs about ourselves today. (p. 240)

At the heart of this reductionistic thinking is a particular form of the materialist position adopted with respect to behavior and its development, reflecting the still dominant influence of mind–body dualism. Behavior, in this view, must be some *thing* and must be in

some *place*, and that place is routinely identified as the brain. This line of thought stems from the reductionistic belief “that physiology is somehow nearer to reality than psychology” (Bannister, 1968, p. 231). This appears to be as true today as it was when Bannister made that statement. Thus, Weisberg, Keil, Goodstein, Rawson, and Gray (2008) found the current popular perception of neuroscience to be as follows:

The presence of neuroscience information may be seen as a strong marker of a good explanation, regardless of the actual status of that information within the explanation. That is, something about seeing neuroscience information may encourage people to believe they have received a scientific explanation when they have not. People may therefore uncritically accept any explanation containing neuroscience information, even in cases when the neuroscience information is irrelevant to the logic of the explanation. (p. 470)

In their words, neurologic explanations are “alluring.” Although the results of their investigation indicated that “experts” were not lulled into accepting false neurologic explanations, there is little reason to believe that psychology as a whole is less susceptible to this illusion than is the lay public. Our discussion of brain imaging (see later) is directed at this point.

Brain and Mind

Since adopting the model of experimental science around 1879, psychology has been identified as a dualistic enterprise, that is, the study of behavior *and* of the mind. Although the discipline has had little difficulty in defining what is meant by behavior (i.e., what organisms *do*), we have yet to achieve anything near consensus about what is meant by mind, or even whether such a thing or process exists. Although ideas of the mind can be traced back to the beginnings of philosophy, there is little dispute that the modern concept of the mind (i.e., mind/body dualism) can be attributed to Descartes (Leahy, 2000; Overton, 2006). Descartes believed mind and body to be truly different substances, as expressed in this statement: “There is no physiology of the mind any more than there is a psychology of the nervous system” (cited in Reise, 1958, p. 122). Of course, with Descartes, the brain had by then become the seat of the mind/soul (Pronko, 1988), although as early as Hippocrates, four centuries before Christ, the brain had been identified as the organ of the mind (Penfield, 1958b). We are in full agreement with Richard Rorty’s assessment that the “mind-body problem is an historical artifact created

by Descartes—and it should be dissolved rather than positively solved” (cited by Niiniluoto, 1994, p. 40). Indeed, the mind–brain relation was thoroughly discussed by Uttal (2005), who concluded this to be a virtually unsolvable problem when cast in a dualistic, nonrelational manner.

It can be argued that the mind was not a phenomenon that was discovered as the result of patient and arduous empirical work, but rather an invention, first by the Greeks and for modern psychology, by Descartes, to avoid the Catholic Church’s power of thumbscrew, and later by others, such as Freud, as a way of legitimizing some extremely creative, imaginative, and most likely wrong ideas (e.g., Bailey, 1965; Thornton, 1984). Indeed, in pointing out that we still have no satisfactory definition of the mind, Uttal agrees that today’s mind was yesterday’s *soul*:

In previous times the word soul served the role that mind does now...I use soul here with the understanding that its theological overtones are to be ignored and that soul is, for all practical purposes, synonymous with what modern science now calls mind. (p. 50)

Skinner’s (1977) understanding is pertinent here:

The Greeks invented the mind to explain how the real world could be known. For them, to know meant to be acquainted with, to be intimate with. The term cognition itself is related to coitus, as in the biblical sense in which a man is said to know a woman. Having no adequate physics of light and sound nor any chemistry of taste and odor, the Greeks could not understand how a world outside the body, possibly some distance away, could be known. There must be internal copies. Hence cognitive surrogates of the real world...The mental apparatus studied by cognitive psychology is simply a rather crude version of contingencies of reinforcement and their effects. (pp. 5, 9)

It is appropriate for us to recognize the brilliant work of neuroscientists such as Broca, Frisch and Hitzig, Flourens, Gall, Spurzheim, and others in elucidating important aspects of brain functioning. “But with what consequences to psychology? The upshot of all this research was to saddle the materialistic brain with the functions of the immaterial mind. Thus was the brain made successor to the less scientifically palatable mind. And that’s the way it has been ever since: soul → mind → brain” (Pronko, 1988, p. 189). However, as suggested earlier, we are in agreement with Kantor (1959) and Schneirla (1949) in believing that psychology is mature enough to be a uniquely psychological science with its own principles that are distinct

from biological ones (Greenberg, Partridge, Mosack, & Lambdin, 2006; Pronko, 1980).

We certainly do not move forward with the same hubris of some reductionistic cognitive scientists who can putatively explain how the mind works (e.g., Pinker, 1999). These attempts generally turn out to be more descriptive statements about the manifestations of cognitive and emotional behaviors as opposed to explanatory statements. Rather, we have formed our perspective on the mind by drawing on a long history of multidisciplinary data and a relational developmental systems orientation. In many ways, our view of mind is consistent with the pragmatic views of early American functionalists. From a definitional perspective, we see merit in Schneirla's (e.g., 1949, 1957) understanding of mind and mental events as simply an overarching term referring to the integration across several developmental levels of sensory, perceptual, emotional, and cognitive behaviors of an organism. This definitional perspective has important ontologic consequences, prominent among which is the conception of mind as a term summarizing the set of cognitive, emotional, and individual $\leftarrow \rightarrow$ context relational variables fused within developmental systems. Of course, then, the mind can thus be understood as a collection of psychological variables with no lesser nor greater explanatory attribute than any other psychological variable. The Noble laureate Gerald Edelman (Edelman & Tononi, 2000) referred to memory, one important aspect of the mind and mental events, in the following way:

Whatever its form, memory itself is a system property. It cannot be equated exclusively with circuitry, with synaptic changes, with biochemistry, with value constraints, or with behavioral dynamics. Instead, it is the dynamic result of the interactions of *all* these factors acting together, serving to select an output that repeats a performance or an act. (p. 99)

Mentalism—split apart from the relational developmental system—can be seen as a crutch that gets in the way of our undertaking the arduous tasks necessary to unmask it. No psychologist has made this point more succinctly than Schneirla (1949), by pointing out that: “‘Mind,’ ostensibly a term for a generalized functional entity, a very impressive term, actually is only an introductory expression for all of man's intellectual capacities and attainments considered as a system” (p. 225). We take some solace in the conception of the mind as an extended phenomenon, not confined to the head, but as part of a person-context system (e.g., Marshall, 2009).

In seeing the mind this way as opposed to some secretion or product of the brain, several philosophical conundrums are addressed. Foremost is the problem regarding the on-

tological nature of the Universe—can there be explanatory entities that are fundamentally distinct from the material universe? Cognitive scientist Roger Sperry outlined the traditional philosophical positions with regard to this question: physical monism, mental monism, and dualism. In discussing these positions in the context of cognitive psychology and neuroscience, Sperry (1991, 1993) argued for an intermediary position, that of emergent monism. This, too, is the position of Bunge (1980). The assumption is that physical monism is the only scientifically defensible philosophical position to take, but that the cognitive and emotional behaviors that we refer to as mind are emergent properties of organism/environment dynamism. It is this viewpoint that underscores the contemporary hardware (neuroscience)/software (mind) metaphor. Although our view of mind is sympathetic to that of Sperry's, in that we are certainly physical monists and agree that what we call mind is an emergent property, our view extends that of Sperry's to what could be deemed relational emergent monism. Sperry's emergent monism view of mind is still fundamentally reductionistic, arguing that mind is essentially the dynamic macrostate of underlying neurological activity. Although this dynamic macrostate is emergent in the sense that its properties are not fully predictable from the individual states of the underlying neurologic matrix, it is still a state that is subordinate to neurology.

By accepting the pragmatic definition of mind as an integration of cognitive, emotional, and organism $\leftarrow \rightarrow$ context relational behaviors within the developmental system, you place the concept of mind and its subsidiary constructs within the operational realm of psychology, which, as we have presented in this chapter, is an independent science with explanatory principles that are uniquely psychological and neither subordinate nor superordinate to other phenomenological levels of analysis. Thus, we see mind as an emergent function of the dynamic transactions over the entire course of development of the individual organism and its ecological context. In a seminal essay, Freeman (2001) outlines what he refers to as three centuries of category errors in trying to relate neurology to cognition and other aspects of the mind. At the heart of his argument is the fact that cognitive neuroscience and its philosophical and scientific predecessors have failed to recognize the importance of both development and context as shapers of mind rather than simply being sources of information. In summary, we see mind as an emergent function of the dynamic transactions over the entire course of development of the individual organism and its ecological context rather than as some vague, obscure, and ill-defined secretion of the brain.

Contemporary Neuroscience and Its Problems

What the Brain Does Not Do

The statement that the human brain is the most complex structure in the known universe and that it defies full understanding is a familiar one. Though admitting there remain a myriad of questions about the brain despite the enormous successes of The Decade of the Brain, the assessment itself seems overzealous. As Bullock (1965/1970) stated:

The gulf between our present level of physiological understanding and the explanation of behavior as we see it in higher forms is wider than the gulf between atomic physics and astronomy and is indeed the widest gap between disciplines in science. (p. 451)

Despite having made that comment in the 1960s, we are no closer to understanding the brain–behavior relation as underscored by Uttal’s (2005) explorations of why the mind–brain problem will never be resolved. Indeed, the workings of the brain itself are still poorly understood—even the simplest of brains still defy the most basic understanding (Koch & Laurent, 1999). Professionals, as well as the lay public, are led to believe that our studies of the brain, although not complete, are extensive. However, 45% of contemporary brain studies involve only three species: the mouse, the rat, and the human (Manger et al., 2008). Much of what we know about brain functioning is the result of comparative studies. Examples include giant axons in the squid, dendritic spines in the central nervous system in chickens, conditioned reflexes in dogs, receptive fields in limulus, and nerve growth factor in the chicken. It is safe to say that the relative lack of such comparative studies today limits our full understanding of the brain and its evolution.

Nevertheless, psychology is today characterized by many as a reductionistic biological or brain science. In arguing that morphology is a phrenologic tool for assessing behavior, Gallup, Frederick, and Pipitone (2008) state, “Behavior is first and foremost a biological phenomenon” (p. 302). Similarly, Uttal understands psychology as a field that “can be completely explained in the language and data of neurophysiology—in principle if not in fact” (2005, p. 155). The most mainstream of psychology journals, *The American Psychologist*, often includes articles that promote the reductionist biological nature of behavior. For example, Heinrichs (1993) claims, “Schizophrenia is a kind of brain disease that should be approached as a problem in neuroscience. There are no

viable alternatives.” (p. 221). Even one of the editors of a major behaviorist journal, the *Journal of the Experimental Analysis of Behavior*, has argued that psychology is a biological science: “Behavior is a biological property of organisms—what else could it be?” (J. Maar, personal communication, June 7, 2006). And, of course, the general public is led to believe this as well:

In the 1950s, the common view was that humans begin as nearly blank slates and that behavior is learned through stimulus and response. Over the ages, thinkers have argued that humans are divided between passion and reason, or between the angelic and the demonic. But now the prevailing view is that brain patterns were established during the millenniums when humans were hunters and gatherers, and we live with the consequences. Now, it is generally believed, our behavior is powerfully influenced by genes and hormones. Our temperaments are shaped by whether we happened to be born with the right mix of chemicals (Brooks, 2006, p. 14).

The alternative view is summed up nicely by Bennett and Hacker (2003):

Such assertions as these—namely, that human beings are machines, or that the behaviour of a human being is no more than the behaviour of their nerve cells, or that decisions are taken in and (apparently) by the brain—are not science but metaphysics...Could neuroscience explain why birthdays are celebrated, why *Tosca* is worth going to, and why a husband might think it appropriate to get tickets to the opera for his wife’s birthday treat? (pp. 356, 364).

The Executive Director for Science of the American Psychological Association has summed up an important reason for current biological reductionism: “[Today’s] newest age of reductionism is being fueled by the federal funding agencies, the Congress, and by the general public. Everyone seems to think that focusing on ever finer grains of sand will hasten cures for the worst of human afflictions and produce enormous leaps forward in our understanding of the human condition” (Breckler, 2006, p. 23).

One of us has argued against psychology’s reliance on the brain as *the* organ of behavior (e.g., Greenberg, 1983). Indeed, although we do not deny the necessity of the brain for behavior (or any life process for that matter), we cannot dismiss the ignored and neglected writings of John Lorber, who in the 1970s accidentally came upon several young adults, normal in all respects, with virtually no brains at all, a result of early childhood hydrocephalus (Lewin, 1980; Lorber, 1983)! The most that critics of these reports

can say is that is simply not possible, but no empirical evidence is ever offered to refute Lorber's reports. Critical comments typically suggest that the full brain is there only in compacted form. On the other hand, a University of Michigan doctoral dissertation (Berker, 1985) concluded:

Despite a marked reduction in neuroanatomical economy both hydrocephalics and hemispherectomy patients have demonstrated development of above average and even superior intellectual capacities. For example, one hydrocephalic (RW) with over 95% of the cranium filled with CSF [cerebrospinal fluid] now has an honors degree in math, superior verbal (VIQ=140) and bright normal performance IQ (PIQ=112) and now has been successfully employed as an accountant. Smith and Sugar (1975) reported a case of left hemispherectomy with similar superior development of verbal, and above average development of non-verbal abilities who has a college degree and has been successfully employed as an executive. Thus our findings of early onset hydrocephalus and studies of patients with hemispherectomy for infantile hemiplegia illustrate the remarkable capacity and versatility of the young brain for functional reorganizations despite marked reductions in cerebral economy.

That these findings have been ignored by the neuroscience community is no surprise to Lewontin (1997): "Repeatable observations that do not fit into an existing frame have a way of disappearing from view" (p. 30).

But as asserted earlier, from the holistic developmental systems approach, it is the *whole* organism that behaves. This is the point of Noë's (2008) statement:

We should reject the idea that the mind is something inside of us that is basically matter of just a calculating machine. There are different reasons to reject this. But one is, simply put: there is nothing inside us that thinks and feels and is conscious. Consciousness is not something that happens in us. It is something we do.

Having just completed two major research efforts, the Decade of the Brain and the Human Genome Project, one goal of which was to elucidate the neural and genetic underpinnings of behavior, it may be understandable why biology, why brains and genes, is seen to control behavior, and why psychology is understood to be a biological science in the reductionist sense of the term. No one would deny the significance of the biological in our understanding of behavior; however, evolution, genetics, hormones, and neurophysiology are not, even together, *foundational* or bedrock explanations of behavior and development.

They are all necessary, although not necessary and sufficient, participating factors in the development of behavior. The Decade of the Brain and the Human Genome Project purported to put to rest the search for the bedrock origins of behavior. The former endeavor sought to place the entire burden of behavior on the brain, the latter on the human genome. Each effort yielded much significant and important information about the brain and the genome, but their impact on our understanding of neural and genetic influences on behavior were minimal (Lewontin, 2000; Strohmman, 1997). Although each effort arose from and attempted to endorse the nature side of the nature-nurture equation, "The Decade of the Brain has led to a realization that a comprehensive understanding of the brain cannot be achieved by a focus on neural mechanisms alone, and advances in molecular biology have made it clear that genetic expressions are not entirely encapsulated, that heritable does not mean predetermined" (Cacioppo, Bernston, Sheridan, & McClintock, 2000).

In support of a perspective that approaches behavioral understanding holistically and relationally, we may consider evidence from several areas, evidence both present and absent.

Lateralization and the Split Brain. It is widely accepted that the brain and its functions are lateralized, and that this lateralization is the result of developmental dynamics (Rogers, in press). For example, chickens develop in their eggs with one side of their heads against the shell exposed to light stimulation. Rogers' research has elegantly shown this prehatching experience to affect brain lateralization in these animals. A similar situation may exist in primates. Michel (1981) and Michel and Goodwin (1979) argued that the position of the fetus in the uterus, the orientation of its head after birth, and left-right hand preference are all associated.

However, Sperry's (1982; see also Gazzaniga, 1967, 1983) idea that the two hemispheres are specialized for different cognitive functions remains in dispute. The most significant argument against this is the empirically based discussion by Efron (1990), which is summarized as follows:

The degree to which studies of split-brain patients have, in fact, confirmed the existence of right-hemisphere speech is a matter of debate: Gazzaniga (1983) has claimed, "Indeed, it could well be argued that the cognitive skills of a normal disconnected right-hemisphere without language are vastly inferior to the cognitive skills of a chimpanzee" (p. 536).

Myers (1984), in a detailed review of the data on 21 of Gazzaniga's split-brain patients, asserts that Gazzaniga has seriously misinterpreted the facts. As you might expect, in his rebuttal Gazzaniga (1984) defends his own interpretation. I mention this dispute to alert the reader that many of the conclusions drawn from the study of split-brain patients, and not merely those pertaining to right-hemisphere linguistic competence, are not as convincing as you might have been led to believe. (p. 40)

Efron discusses the misinterpretations of their own data by researchers in this field and points out the many design flaws in their experiments. His conclusions are buttressed by his own research, which draws fundamentally different conclusions about hemispheric specialization.

A more telling criticism is that of Myers (1984), cited earlier by Efron. Myers reveals that there are a surprisingly small number of "split-brain" patients to begin with, and more significantly, most of them have only partially split hemispheres. We have seen dogma developed based on a small N in psychology before. Today's psychology textbooks still cite Penfield's "findings" that memories "stored" in the brain can be released by the application of a mild current to the cortex (e.g., Penfield, 1958a; Penfield & Perot, 1963). Some of his patients reported vivid memories during brain stimulation, and this led him to conclude that memories are highly stable and the brain contains a complete record of our past experiences. Rarely, if ever, mentioned are the facts that, of his 520 temporal cortex-stimulated patients, only 40 (7.7%) reported such memories (Loftus & Loftus, 1980). It is a very weak science, indeed, based on 7% of events. Could it be that the auditory sensations produced brain stimulation function as a kind of auditory projective test in which the patient interprets auditory buzzing as memories? This is the suggestion of Pronko (1973). About memory, we prefer Skinner's (1974) understanding, that memories are not stored and later retrieved as from some filing cabinet, but are rather remembered, stimulated by substitute stimuli.

Finally, it was recognized early that split-brain findings have been characterized as follows: (1) by their capriciousness, (2) by replication failures, (3) by widespread individual performance differences between experimental subjects on similar tasks, (4) by the lack of consistency within the same individuals on experimental tasks, and (5) by the then and continued absence of a global theory accounting for such phenomena (Friedman & Polson, 1981). Pronko (1973) points out that split-brain subjects only show split-brain phenomena in the special settings of laboratory conditions. In real life, such subjects

are intellectually and cognitively "normal." In the end, one has to wonder about the meaning and validity of these split-brain reports.

Localization of Function. The findings of Frisch and Hitzig in the 1870s gave substantial credence to the notion that the brain is partitioned into areas that control various bodily and mental functions (Uttal, 2001). Every textbook shows and describes which brain areas and structures control which psychological processes (e.g., Kalat, 2009). However, the picture of this has changed in 150 years. Even those who still adhere to some form of localization admit it holds only for the basest of functions—reflexes, sensory inputs—and not for higher cognitive processes (Linden, 2007). Valenstein (1973) stated:

The impression exists that if electrodes are placed in a specific part of the brain, a particular behavior can be reliably evoked. Those who have participated in this research know that this is definitely not the case. (p. 87)

He describes research, especially involving hypothalamic stimulation, showing that evoked behavior differs depending on the presence of different objects in the environment. For example, stimulating the ventromedial hypothalamus is supposed to elicit eating, excessive eating in some cases; and it does in the presence of food, but it evokes drinking in the presence of water and gnawing in the presence of objects to gnaw on (Valenstein, Cox, & Kakolewski, 1970). Interestingly, as early as 1808, Cuvier was "an early opponent of the cerebral localization of mental phenomena" (Reise, 1958, p. 129). Reise points out that a similar view was expressed at the 1861 meeting of the Paris Society of Anthropology by Gratiolet, in almost identical terms. How prescient these men would turn out to be.

Sex/Gender Differences. The terms *sex* and *gender* are not so easily defined. One seemingly refers to biology (*sex*), the other to culture (*gender*; Rogers, 1999). Nevertheless, there are certainly differences, behavioral and biological, between male and female individuals. However, as Rogers explains, these differences are not directly explained by genetic (or other biological) foundations, but rather by a fusion of nature and nurture effects. Readers of this handbook are undoubtedly aware of the fact that this area of study has been, and remains, controversial. As Rogers points out, "No other area of biology is more influenced by social attitudes than the study of differences between human groups" (p. 6). This is, of course, as true for psychology and development as it is for biology, as a

recent discussion in the journal *Nature* of the genetics of intelligence makes clear (Ceci & Williams, 2009; Rose, 2009). Rogers's own research (1999, in press) confirms brain differences between the sexes, though she has identified experiential reasons for those differences. Others, she points out, carelessly ignore conducting research to determine the reasons for such differences.

Rogers's arguments are buttressed by those of Anne Fausto-Sterling (1985). Of course, male and female individuals show differences—in relatively trivial ways such as hair length and body shape. But the search for “root causes” of behavioral differences has been fruitless. She argues instead for “a more complex analysis in which an individual's capacities emerge from a web of interactions between the biological being and the social environment” (p. 8).

Neural Imaging. The development of neural imaging techniques, such as CAT (computer-assisted X-ray tomography) scans, PET (positron emission tomography) scans, MRIs (magnetic resonance images), NMR (nuclear magnetic resonance) scans, and others, were heralded as ushering in a new age of understanding brain function (Uttal, 2001). Indeed, for years it was difficult for psychology articles involving brain activity to be published in prestigious journals such as *Science* without accompanying them with brains scans. However, as Uttal indicates, such scans are not the same as looking at photographs of one's honeymoon in Tuscany. They must be interpreted; the devices producing the scans must be calibrated, and that is subject to human error and individuality. In short, he tells us that brain scans leave much to be desired. And woe to the resulting scan if the person being scanned moves his or her head! This is exactly the argument that Roskies (2007) presented: fMRIs are not photographs at all. They allow us to visualize magnetic properties of water in the brain. That such scans light up when parts of the brain are active “is an illusion” (p. 863). The many inferences that have to be made in reading or interpreting brain scans leaves a great deal of room for making errors (Dobbs, 2005).

Uttal is not alone in his cautions about the meanings of brain scans. Although not critical of the scientific validity of the vast amount of neuroimaging reports in recent years, Page (2006) nevertheless points out that that does not “constitute good cognitive science” (p. 428). He indicates that, for the most part, imaging research is geared to address “where” questions and not “how” questions. That is, that a part of the brain lights up in a scan indicates where in the brain some function is being processed.

However, in his review, Page questions “whether the engagement of two different regions, even regions well separated in the brain, *necessarily* implies two different functions” (p. 431). Whether scans might be identifying epiphenomena is a legitimate question to raise. Page raises an important criticism, not only of neuroimaging research but of research in general, that touches on the sociology of science. Scanning devices are expensive, and the expense could color one's judgements and interpretations of findings to justify the outlay of huge sums of money for equipment. Indeed, scans do not necessarily even indicate brain activity. Sirotnin and Das (2009) report findings that blood flow changes in the brain are not always linked to changes in neuronal activity.

A more serious criticism of neuroimaging is raised by Vul, Harris, Winkelman, and Pashler (2009). They analyzed the results of 54 articles reporting imaging and found the statistical analyses to be seriously faulty, especially with respect to the overstating of correlations between scanning results and brain functions. They state that in half of the reports they examined “correlation coefficients mean almost nothing, because they are systematically inflated by the biased analysis” (p. 281). Finally, as we discussed above, scanning images are “alluring.” We tend to be persuaded by things we can see, i.e., scanned brain images, regardless of what those images might mean. As McCabe and Castel (2007) point out, images appeal to our intuitive understanding that the brain is doing something important!

It is quite clear that when the record is closely examined, many facts about neuroscience are not facts at all. This is, of course, not peculiar to neuroscience, or to psychology, but perhaps to science in general. Pertinent examples for this discussion include the often erroneously reported facts about Broca and his role in uncovering the locus of speech defects (Thomas, 2007; Willems & Hagoort, 2009), and the incorrectly reported story of Phineas Gage, which occupies a special place in the history and our understanding of the brain and behavior (Macmillan, 2008). We have provided only a small sample of other similar “facts.”

What the Brain Does Do

The Brain and Cognition. “The anatomical and functional architecture of the brain is neither established genetically nor fixed at birth. Instead, the system has extraordinary plasticity; its formation reacts in response to the structure and influence of its environment...Brain and culture are co-producing partners” (Baltes, Reuter-Lorenz, & Rösler, 2006, p. 20). This, of course, is consistent with our relational, holistic, epigenetic, developmental system

perspective regarding not only behavior but anatomy, and for this chapter, especially the brain. As Benno (1990) makes abundantly clear, the development of the brain is itself regulated by a complex set of epigenetic processes.

Coltheart (2006) said, “Rather a lot of people believe that you can’t learn anything about cognition by studying the brain” (p. 330). In his discussion, Coltheart described several research projects that failed to provide support for one or another cognitive theory based on neuroimaging data collected. He concludes that the techniques have taught us nothing about the mind. He also cited several authors who support the idea of the fruitlessness of such work. Fodor (1999), for example, is cited suggesting that such work seeks merely to collect data showing that certain brain areas light up during certain tasks—that is, experimental data are taken *ipso facto* as a scientific contribution. Coltheart also pointed out that, although a great number of imaging articles are published today, few are critical of the technique and of its use in studying cognition. Three recent exceptions are publications by Page (2006), Uttal (2005), and Vul, Harris, Winkielman, and Pashler (2009).

However, as in an earlier discussion of this topic (Greenberg, Partridge, Weiss, & Haraway, 1998), we focus on a single crucial question: How is it that one species among millions developed the ability to use language (Deacon, 1997)? Was it due to increased brain size and functional brain organization? An important relation exists between brain development, complexity, and language, but this does not appear to be the whole story. There is disagreement regarding the anatomy and the structure-function relations of brain areas and behaviors. Griffiths and Warren (2002), for example, discuss this with respect to the *planum temporale*, a structure implicated in speech. The brains of chimpanzees contain this structure (Gannon, Holloway, Broadfield, & Braun, 1998), but they are incapable of speech. Therefore, although it is tempting to draw broad conclusions and make judgements about the brain, behavior, and development, it appears that little about the brain is so simple. Consistent with our understanding that the brain is an integrating organ system, in their analysis of the *planum temporale*, Griffiths and Warren make the case that it is a “computational ‘hub’ that directs further processing in other cortical regions” (p. 348). Of course, modern brain scans show that many brain areas are active in any function, cognitive or otherwise (Uttal, 2001; Vul, Harris, Winkielman, & Pashler, 2009).

Cultural complexity has also been thought to be an important influence in the appearance of language. For example, human children fail to develop language in the extreme absence of adult role models and interaction (Lieberman, 1998). And many nonhuman primates and other mammals do live in quite complex social communities without developing language. Yet, if we conceive of language, culture, and brain complexity holistically and relationally as parts of a large, complex developmental system, small incremental changes in all three may be seen eventually to reach a critical level of both capacity and interconnectivity, leading to a cascade of large-scale increases across all of the system components. Thus, brain complexity, language, and cultural complexity all begin to drive each other to exponential increases. Large-scale and sudden changes often lead to (novel) qualitative changes in system behavior (Bak, 1996). Such changes are analogous to the concept of phase transitions in physics—what we have referred to as emergent properties (Greenberg, Partridge, & Ablah, 2007; Partridge & Greenberg, in press). Thus, the shift from protolanguage skills of chimpanzees, which on close examination differ dramatically from “true language,” to language used by humans would be an emergent “phase-transition.” The development of language by bonobos (Savage-Rumbaugh, Shanker, & Taylor, 1998) is preceded by their immersion in a complex and unrelenting social setting (see MacWhinney, Chapter 14 of this volume, for an extended discussion of language development across the life span).

Tobach and Schneirla’s (1968) formulation of behavioral levels (applied to the full range of behaviors in Greenberg & Haraway, 2002) correlates highly with nervous system evolution and complexity. There is little disagreement regarding the evolutionary trend toward more complex nervous systems and larger brains (e.g., Rose, 1989). Related to this are two fruitful ideas, seen by some as competing but by us as complementary. The first is that evolution provided larger brains and with that, increased amounts of neocortex, or association cortex. Indeed, among the primates there is

...a profound enhancement of the neocortex in relation to the rest of the brain as one moves from the most primitive primate forms, the prosimians, to the New and Old World monkeys in turn, and to the lesser apes, great apes, and humans. The brain becomes more complex in its dendritic interlacings, its convolutions, and its gyri. The cortex becomes disproportionately large relative to the rest of the brain. (Rumbaugh & Pate, 1984, p. 571)

These developments provide greater computational or information-processing power by these brains.

The second fruitful idea is that the crucial dimension for the appearance of higher cognitive processes in these larger brained species is not mere volume of neocortex, but the ratio of log brain mass (especially neocortex) to log body mass, referred to as the “encephalization quotient,” or EQ (Jerison, 1973). Scaling features such as brain size and body size against each other is known as *allometry* (Thiessen & Villarreal, 1998). As Rumbaugh and Pate (1984) and others have pointed out, this latter allometric trend does not become clear until the variance has been smoothed by using a logarithmic transformation on brain mass and body mass. The encephalization quotient provides an objective measure, “a true dimension based upon objectively measured structural attributes” (Plotkin, 1983, p. 128). Olson (1976) has shown that progressive encephalization, in particular an increased amount of cerebral cortex, represents a greater capacity to process information. Killackey (1990) presented an argument that agrees with this line of thought, showing that neocortical expansion and improved information processing follow along phylogenetic lines. The ratio of neocortical mass to total brain mass (the neocortical ratio), which is a refinement of the encephalization quotient, is correlated to yet a higher degree with cognitive processes. The increased neocortex relative to total brain mass results are what Deacon (1997) refers to as *net computing power*. Accordingly, the neocortical ratio is thought to be a proxy measure for the ratio of neurons available and neurons needed for basal functions such as sensorimotor regulation, autonomic responses, and metabolic demand.

The brains of primitive vertebrates consist of three swellings: forebrain, midbrain, and hindbrain. All evolutionary advance has preserved this arrangement, simply increasing the size of these swellings. Advanced vertebrate brains are thus larger, though the same pattern of hindbrain, midbrain, and forebrain is preserved. Larger brains mean more neurons, and this, in turn, means more pathways, circuits, and tracks in the nervous system (Deacon, 1990). More of these processes resulted in greater and more refined differentiation, permitting greater integration of neural functioning. As the nervous system increased in size, its information-processing capacities differentiated and increased as well. Improved information processing was recognized early by Pantin (1951) to be a crucial indicator of evolutionary advance. According to Michel and Moore (1995), “The essence of neuronal function is to integrate input from one group of cells and to transmit the resulting activity to yet other cells. The pattern of connections that a neuron maintains with other cells

defines, to a very great extent, the nature of its functioning” (p. 260). Of course, this was the point of Sherrington’s important book, *Integrative Action of the Nervous System* (1906). The increase in neural integration that accompanied increased brain size allowed for greater behavioral plasticity and diversity. Thus, we expect, and find, increased behavioral plasticity and complexity as we ascend the behavioral levels, across a corresponding increase in brain size (Jerison, 1994). Other evolutionary trends are those of increasing body size and of numbers of specialized cell types. Increases in size and complexity require increases in brain size to permit the coordination of more cell and muscle types. Some now understand the brain as a relational, bidirectional processing system that functions between inputs and outputs (Marshall, 2009). This conception underscores the plasticity of the nervous system. Contemporary thinking about complexity and cognition is summed up nicely by Goodwin (2009): “When an organism has a nervous system of sufficient complexity, subjective experience and feelings can arise. This implies that something totally new and qualitatively different can emerge from the interaction of ‘dead,’ unfeeling components such as cell membranes, molecules, and electrical currents” (p. 3).

This perspective is also applicable to the difficult concept of “consciousness,” such that we would hypothesize that critical levels of neuronal connectivity and activity lead to qualitative shifts from “unintelligent” functions to “intelligent” functions. Although not discussed here, this has been dealt with from a hierarchical organizational point of view by both Bickerton (1995) and Edelman (1992; Tononi & Edelman, 1998). Our own earlier treatment of this topic showed how other human cognitive processes, particularly the broad category of “culture,” can be understood from this relational, holistic, developmental systems perspective (Greenberg, Partridge, Weiss, & Haraway, 1998).

Of course, although we have presented psychology not as a biological but as a developmental, psychological science, we underscore the significance of biology, and of brain, for psychological development. In the end, however, we are forced to agree with Hardcastle and Stewart (2002), who ask, “What do all the brain data we have amassed tell us about how the brain works? Precious little so far” (p. S80).

BIOLOGY AND DEVELOPMENT

A common question, whether implicitly or explicitly posed, in theoretical articles regarding biology, evolution, and development, asks what the role of biology is

in shaping development. Such questions take the form of hypotheses regarding the relation between a given allele and trajectories of behavioral outcomes such as adolescent smoking (Malaiyandi, Sellers, & Tyndale, 2005) or the heritability of attachment (Finkle, Wille, & Matheny, 1998), or the findings of functional MRI studies correlating age-related declines in spatial abilities with changes in regional neural metabolism during a spatial memory task (Moffat, Kennedy, Rodrigue, & Raz, 2007). In the case of evolution, if the research questions posed are even reasonably empirically testable, they tend to be framed in the form of the constraints that evolution places on behavioral development (Buss, 2005). Alternatively, evolutionary perspectives simply articulate putative adaptive explanations for developmental phenomena (Buss, 2005). In all of these situations, there is an underlying assertion that development is subsidiary to evolutionary trajectories and biological factors. In other words, ontogeny is a function of phylogeny and behavioral development is shaped by the organism's biology. From this perspective, biology is the fundamental and guiding force that drives individual differences in developmental trajectories of behavior.

However, a relational, holistic position takes a dramatically different perspective on the relations between biology, evolution, and psychological development. From this perspective, development is an active system of processes superordinate to biology and evolution. Thus, it is not that the gene or evolution explains development, but that the developmental system explains the functioning of both the gene and evolution. From this perspective, it is the developmental system that integrates biological functions into coordinated patterns that support behavior. It is the process of development that shapes biological organization and provides a temporal context for biology-behavior-ecology interrelations. So the question really becomes, how does development shape biology and the relation of genes and neurons with behavioral outcomes in a given environmental context?

In endorsing this relational, holistic position, we believe that the focus of study in psychology should be on the pattern of interrelations between biological structure, psychological states, and ecological contexts. A clear characterization of development, be it biological or behavioral, is that organisms are initially composed of relatively undifferentiated biological and behavioral features that, over time, become increasingly differentiated and reintegrated into a coherent biological and behavioral system. It is the probabilistic epigenetic and self-organizing principles of development within a dynamic ecological

context that shape the process of differentiation and integration that characterize a given individual's genetic, neurologic, and behavioral attributes, rather than the other way around.

As early as 1929, Woodger made an important distinction between the study of development in the form of embryogenesis and the study of genetics. The study of development has as its focus the patterns of biological and behavioral differentiation within a single organism over time. This notion of development is echoed in the recent work of Nesselroade and colleagues (e.g., Molenaar, 2007; Nesselroade & Molenaar, 2006, Chapter 2 of this volume) emphasizing the importance of methods for the study of intraindividual variability. The study of genetics, in contrast, has as its focus the pattern of differences in attributes between organisms at a given point in time. In relating the two sciences, Woodger (1929) stated that even at the turn of the 20th century, the source of individual differences in patterns of differentiation were sought both in the nucleus and the cytoplasm of the germ cells, yet these attempts were unsuccessful. But despite the consistent lack of empirical support for the genesis of developmental differentiation in the physical attributes of the germ cells, it is an assumption that has yet to yield. However, what has consistently been demonstrated empirically from experimental embryology at the turn of the 20th century to contemporary molecular genetic studies is that the physical attributes of the cell, including protein formation and structure, are a direct result of developmental transactions of the biological aspects of an organism and the environmental context of that organism. As Woodger (1929) put it:

The cells of a given developing embryo are internally related to one another in the sense that the rate and plane of division, at least, of a given cell, depend upon its relations to the neighbouring cells, and hence on its position in the whole....At a certain period of development the cells of an embryo undergo intracellular elaboration depending partly on their mutual relations, and partly on their intrinsic properties so that the latter may be the same in all cells, [and] which of them are realized in a given cell will depend upon its relations to the whole, which will of course differ from place to place. (p. 384)

And so it would seem that nearly 90 years of empirical findings suggest that, rather than searching for the source of intraindividual differentiation in interindividual differences, we should perhaps be looking for the source of interindividual differences in the patterns of intraindividual differentiation.

Role of the Gene in Development

At least since the broad acceptance of the modern synthesis in biology, the gene construct has served as the central biological organizing feature assumed to guide biological and behavioral development. Indeed, it was tacitly assumed by behavior geneticists that once the human genome was sequenced, behavioral science would be able to incorporate genetic profiles into a general linear model calculus and be able to predict with a reasonable amount of statistical precision the general trajectory of behavioral development, especially those that had been demonstrated to be highly heritable, and thus largely under genetic control. This assumption was based on the premise that packets of nucleotides contained developmental information guiding biological development. Behavioral geneticists, being primarily interested in genetically guided neurologic development, could then argue for genotypic control of the behavioral phenotype via the neurologic endophenotype. The sequencing of the human genome (Venter et al., 2001) has not yielded the scientific fruit for behavioral science that many leading behavioral geneticists envisioned, as we discussed earlier. Rather, there has been a realization among cell biologists that genes do not carry biological or developmental information, and that they have the capacity to differentially respond to environmental and developmental signals originating at multiple levels of biosocial organization. As a result, there has been a resurgence of interest in epigenesis as a developmental process and of epigenetics as a mechanism through which genes and contexts transact through development.

Although the concept of epigenesis originated in biology, with respect to behavioral development, the usefulness of *probabilistic* epigenesis was recognized and promoted throughout the 20th century by psychologists such as Zing-Yang Kuo (1967), Gilbert Gottlieb (1992), Susan Oyama (2000), and T. C. Schneirla (Aronson, Tobach, Rosenblatt, & Lehrman, 1972), though Schneirla never specifically used the term *epigenesis* in his writing. Probabilistic epigenesis has gained support from an exciting set of developments in contemporary science subsumed under the rubric of “dynamic systems theory and relational developmental systems theory,” in which complex developmental processes are understood as composed of interrelations among many active system components of the whole developmental system. The implication of this position is that in a dynamic and changing environment, rather than genes specifying a particular developmental outcome, be it structural or behavioral, *every outcome is an emergent*

result of the transaction between genes and their cellular, organismic, ecologic, and temporal contexts. This view of epigenesis is epitomized by recent discoveries in biology that even identical genomes in extremely similar environments do not always follow the same developmental pathways. Ko and colleagues (Ko, Yomo, & Urabe, 1994), studying enzyme activity in bacteria, found that despite identical genomes and extremely uniform culture conditions, individual cells developed different levels of enzyme activity and grew into colonies of different size. Ko’s studies showed that cell state in bacteria is determined not only by genotype and environment. Rather, “Changes of state can occur spontaneously, without any defined internal or external cause. By definition, these changes are epigenetic phenomena: dynamic processes that arise from the complex interplay of all the factors involved in cellular activities, including the genes” (Solé & Goodwin, 2000, p. 63).

In an impressive review of developmental processes shaping biological phenotypes, Rudel and Sommer (2003) have identified ten basic developmental principles that can adequately describe biological development.¹

What is perhaps most intriguing about these principles is how few of them are genocentric. In fact, nearly all of them involve either epigenetic factors or epistatic genetic regulation. For the purposes of this chapter, we briefly review four of these core principles:

Asymmetric cell division. One of the key factors in establishing the morphologic and functional capacities of differentiated cell lines is the relative spatial position within the developing embryo. Most cellular division produces two homogeneous daughter cells from a single progenitor cell. This results in a cellular symmetry by maintaining an undifferentiated state from mother to daughter cells. However, asymmetric cell division occurs when the differential concentrations of cell fate determinant factors align with the mitotic spindle, producing daughter cells with different exposures to cell fate factors, and thus differentiating the ultimate cell line morphology

¹ Rudel and Sommer (2003) outline 10 principles of biological development: Fate Maps, tracing the lineage of a given cell line; Asymmetric Cell Division, Cellular Induction, Developmental Genomics, Cell Competence, referring to the cell’s differential responses to biochemical gradients; Genetic Redundancy, Positional Information, Differential Determination, Lateral Inhibition, and Genetic Networks. Rudel & Sommer (2003) claim that with these basic concepts much of the biological development of organisms can be described.

and function. This asymmetric cell division process has been shown to occur both spontaneously and in response to extracellular signaling mechanisms (Knoblich, 2001). Therefore, although both daughter cells contain the same genetic capacity to achieve the same cell fate, differential exposures to cell fate factors elicit differential genetic activity within those identical genomes, which leads ultimately to cellular differentiation.

Cellular induction. Cellular induction is a fundamental cell signaling process whereby biochemical signals are produced through the activity of a given cell or tissue that influences the developmental fate of neighboring cells. Rudel and Sommer (2003) review a study of eye development in two populations of Mexican cavefish (*Astyanax mexicanus*). The epigeal type of *A. mexicanus* lives in surface waters and develops a normally functioning eye. The hypogean type, however, dwelling in dark, underground cave waters, develops a nonfunctional occluded eye, a common adaptation in animals living in darkness. Yamamoto and Jeffery (2000) performed a lens transplantation experiment in which they placed the hypogean lens vesicle in an epigeal optic cup and also placed an epigeal lens vesicle in a hypogean optic cup. Via local cellular induction processes, transplanted epigeal type fish developed occluded eyes that did not have an iris, cornea, or anterior chamber. Similarly, the transplanted hypogean fish developed fully functional eyes. Such induction processes have played a vital role in our understanding of the neuropharmacologic responses to chronic nicotine exposure (Joshi & Tyndale, 2006), as well as cancer cell proliferation (Barcellos-Hoff, 2008).

Lateral inhibition. Lateral inhibition is also a cellular signaling process in which the activity of a cell inhibits or restricts the ability of neighboring cells to develop along a similar pathway. This cellular signaling process is critical to cellular differentiation, which is necessary for biological and behavioral development. For example, recent work by Amoyel and colleagues (Amoyel, Cheng, Jiang, & Wilkinson, 2005) found that the cellular signaling molecule Wnt1 expressed by boundary cells in the zebrafish hindbrain is a mechanism through which cellular differentiation occurs in zebrafish hindbrain development.

Positional information. As a result of cellular signaling processes such as cellular induction and lateral inhibition, every cell is exposed, throughout development, to an ever-changing biochemical information field. Based

on the specific signaling factors present, the relative gradients of exposure, and the developmental history of the cell in terms of patterns of genetic expression and cell fate, cells follow self-organized developmental sequences as a function of their spatial and temporal location in the developing organism. The role of positional information can be seen in the cellular differentiation of limb formation in arthropods via the differential expression of the *Ultrabithorax (Ubx) Hox* genes. The differential expression patterns arise from epigenetic influences that vary along spatial dimensions (see Rudel & Sommer, 2003).

These developmental processes or mechanisms are just a few exemplars of the developmental principles that Rudel and Sommer (2003) outlined for understanding biological development. We highlight these four processes because they typify the extent to which epigenetic and sequential processes are regulating patterns of genetic expression, and thereby leading to differential cell morphology, cell function, and cellular organization. This is in stark contrast with the genocentric reductionistic viewpoint of the central dogma of genetics and behavioral genetics in which the gene is the regulator of development. Indeed, what we view here at the most basic biological level is that genes require differential exposure to epigenetic factors to function at all, and a given extragenetic factor will yield differential cell fates depending on the genetic background in terms of sequencing history of the cellular DNA. In other words, in biological development, it is quite clear that genetic and extragenetic processes coregulate each other and become organized through development rather than being the organizers of development. If this complex transactional developmental process serves as the organizing feature of basic cell morphology and embryogenesis, it seems a far reach, indeed, to speculate on the regulating role of genes for a complex social phenomena such as social network membership (Fowler, Dawes, & Christakis, 2009).

Development in Complex Adaptive Systems

As stated earlier, the science of molecular genetics is still in its empirical infancy. Before the turn of the century or so, the functioning of specific genes had to be largely inferred from indirect observations. The ability to work with specific genes has revealed an astounding complexity and requires a paradigmatic realignment of the reductionistic conceptualization of “the gene as blueprint or instruction

set.” Rather, what we are learning, as highlighted in the earlier discussion, is that genes serve as relatively passive biochemical production mechanisms. More developmental information is stored in the gene than there is in the metal stamping machine in an auto factory—they simply produce parts. This is not to negate their importance in biological and behavioral development. It is simply to recognize that they are but a single element in a vast developmental complex operating on multiple spatial and temporal scales. Furthermore, this biobehavioral complex becomes organized and displays a consistent morphologic and behavioral regularity through the developmental sequencing of multiple internal and local coregulating transactions among genes, cells, tissues, organs, organ systems, organisms, and their environmental and historical ecologies. This is much the same realization that the Chinese comparative psychologist Z. Y. Kuo (1970) articulated: “Every response is determined not only by the stimuli or stimulating objects, but by the total environmental context, the status of anatomic structures and their functional capacities, the physiological (biochemical and biophysical) conditions, and the developmental history up to that stage” (p. 189).

Despite the hubris that often accompanied the Human Genome Project, The Decade of the Brain, and other heralds of reductionistic biocentric social science, we are seeing that at the genetic, proteinomic, neurological, cognitive, and social levels of analysis, these phenomena typify all of the fundamental attributes of a complex adaptive system (CAS) (see Holland, 1995). The atomistic decompositional quest for the genetic or neurological basis of behavior has ironically taught us that we can understand biological and behavioral phenomena only by treating the biopsychosocial system holistically as an integrated whole. CAS models provide a uniquely suited methodology for this task. Over the past couple decades of work on CASs, one lawlike finding has been that the organization and behavior of the system is a function of its developmental transactions, and as such, it is the act of developing that shapes the fate of the system and influences the behavior of the elements rather than the elements guiding the developmental process. This is a profound, if topsy-turvy, lesson for those of us working at the interface of biology and behavior.

Psychology Is a Developmental Science

Contemporary developmental science has successfully provided a dialectical synthesis of earlier organismic and mechanistic theories (Overton & Reese, 1973) by positing that behavioral development is a function of an active or-

ganism interacting with an active sociohistorical ecology. This family of theories includes perspectives such as relational developmental systems theory (Lerner, 2006; Lerner & Overton, 2008; Overton, 2006), the life-span approach (Lerner, 2002), the person-oriented approach (Magnusson, 1995), transactional models (Sameroff, 1975), and the bioecologic developmental systems model (Bronfenbrenner & Morris, 2006). The success of these theoretical formulations is indicated by the radical change in the scope and content of developmental psychology.

Concurrent with advances in developmental science, science in general has been revolutionized by developments in the study of nonlinear dynamic systems, as discussed earlier. Under the general rubric of nonlinear dynamics are several subfields: chaos theory, the study of complex behavior resulting from simple and deterministic processes; fractal geometry, the study of geometrical forms invariant across scale; and complex systems theory, the study of stable, organized behavior resulting from complex and stochastic processes. It is the latter that seems to hold the most relevance for current formulations of developmental science.

Relational developmental systems theory has built steadily on the ideas of such early biological and behavioral theorists as Kantor (1924, 1926), Kuo (1967), Morgan (1923), Needham (1929), Novikoff (1945), Schneirla (Aronson et al., 1972), and Woodger (1929). These early foundations provided a fertile source from which developmental systems theorists such as Bronfenbrenner (Bronfenbrenner & Morris, 2006), Cairns (Cairns, Elder, & Costello, 1996), Lerner (Ford & Lerner, 1992), Overton (2006), Oyama (1985), and many others have successfully drawn. A new vigor has been infused into this longstanding developmental framework through the incorporation of analytic and conceptual tools from the recent study of CASs. Until the 2000s, relational developmental systems models were often restricted to metaphorical statements. However, advances in complex systems science have allowed for more specific and grounded assertions about how complex behavioral systems develop over time. This has the potential to profoundly impact developmental science.

The ideas of the scientists (behavioral and biological) and philosophers we cited earlier have coalesced since about the late 1980s in a form germane to psychology under the rubric of “developmental systems theory” or “relational developmental systems theory.” Despite the terminology, this is not a specific theory, nor is there universal agreement among these diverse sources (Keller, 2005; Griffiths & Gray, 2005).

It is possible, however, to identify at least seven interrelated themes among them (Robert, Hall, & Olson, 2001):

1. *Developmental contextualism*: organisms are fused with their environments, all features of which affect the developmental course of their behavior, as well as their biologies (Lerner, 1998). The idea of a genetic program becomes unnecessary. Indeed, from this perspective, the claims of geneticists and behavior geneticists can be seen as “grandiose” (Nelkin, 1993).
2. *Nonpreformationism*: the role of probabilistic epigenesis in the course of development. The “rules” governing the developmental process are not locally encoded in some external control process but rather are derived from the recursive mutual interactions of all the system variables as an organized whole. Thus, it is the process of development itself that drives the course that development takes.
3. *Causal co-interactionism*: developmental causes interact in complex, nonadditive, ways.
4. *Causal dispersion*: the many causes of development are diffuse and fluid. Genes and brains, then, are participating and not causative factors in development.
5. *Expanded pool of interactants*: genes themselves are influenced by other genes and all the constituents of the cell, among numerous other factors.
6. *Extended inheritance*: inheritance is not the sole purview of genetics. Phylogenetic change can also be induced by environmental causes, as discussed by Honeycutt (2006).
7. *Evolutionary developmental systems*: transmission across generations is not simply of traits but of developmental systems themselves. A complete understanding of evolution requires an understanding of development (evo-devo) and vice versa (devo-evo) (Robert, 2004).

Psychology, like biology during the early 20th century (see Woodger, 1929), has matured into an independent natural science and is poised at the threshold of a paradigmatic shift. On the one hand, there are those suggesting that our understanding of human behavior ultimately lies in the gene or the neuron and, as a consequence, can be fully accounted for by panselectionist evolutionary biology. In strong contrast, we argue that psychology as a discipline must be understood as a developmental science in which ontogeny itself serves to weave together biology and ecology into coherent behavioral trajectories across

the life span of the organism. This paradigmatic transition requires a fundamental shift in the metatheoretic principles guiding psychological theory and the corresponding methodologies away from a conception of static, independent, and additive relations among biological, psychological, and social variables to an orientation that is dynamic, self-referential, and interdependent. In this chapter, we have provided a synopsis of just such a metatheoretical overview and associated methodologies. Furthermore, although explanations of behavior from a population genetic, braincentric, or evolutionary perspective seem reasonable on the surface, when the full weight of empirical data is examined, these views are left wanting. We have attempted to show the fundamental limits of each of these perspectives and how, by adopting a developmental systems perspective, a more complete and coherent account of behavior can be given.

Neuroscience. Many of the ideas we have presented have been incorporated into contemporary neuroscience. Notable among these are the organism-environment system theory that Jarvilehto (1998) proposed and Freeman’s (1991, 1992) work on brain dynamics. The organism-environment system theory asserts that the distinction between organism and environment is artificial, and that one cannot understand the neurophysiological functioning of organisms independent of their ecological context. Similarly, the organism’s ecology can only be meaningfully understood in relation to its neurophysiology. This idea is consistent with the integrative systems view articulated in our approach to comparative psychology (Greenberg, Partridge, Weiss, & Pisula, 2004).

Freeman has been one of the pioneers of applying systems notions to the study of brain functioning. In the examples of his work cited above, he implicitly utilizes many of the principles of organization and integrative levels that we have proposed here in understanding how we get complex brain dynamics from neuronal functioning. These ideas have led to a new understanding of how unintelligent agents such as neurons can, through aggregate behavior, lead to intelligent functions (see also Dean, 2000, and Holland, 1995). Some of these ideas and formulations form the very foundations of contemporary neuroscience (Pribram, 1993, 1996). Uttal’s (2001) critique of the localizationist hypothesis also incorporates a dynamic systems approach to neural functioning. Thus, rather than consisting of numerous independent cognitive

modules, the brain is conceptualized as a dynamic set of circuits functioning as a unit.

Perception and motor development. The study of perceptual and motor development has also been imbued with many of the ideas we have proposed. The leading advances in this area of study focus on the origins of coherent patterns of motion through a dynamic coupling of independent functional units (Goldfield, 1995; Kugler, & Turvey, 1987; Smith, & Thelen, 2003; Thelen, 1989, 1990, 2004). Many of the ideas such as emergence, integration of activity on multiple temporal and spatial scales, and self-organization are fundamental to our understanding of human perception and action. Interestingly, Gibson's (1966) "ecological approach" to perception is again in vogue.

Developmental science. Since the late 1980s, there has been a burgeoning of theoretical developments across a diverse set of disciplines, including developmental psychology, sociology, developmental epidemiology, psychobiology, and embryology, that have a common conceptual foundation—and in many cases, methodological approach—with the comparative psychology we have outlined here. Although these theoretical formulations differ in specifics, they share a core set of common assumptions. These interdisciplinary advances can be referred to as an "emergent convergence and isomorphism" (Cairns et al., 1996, p. ix). Indeed, theoretical frameworks such as relational developmental systems (Lerner, 2006; Lerner & Overton, 2008; Overton, 2006), bioecologic systems (Bronfenbrenner & Morris, 2006), life span (Baltes, Reuter-Lorenz & Rösler, 2006), person centered (Magnusson, 1995), transactional (Sameroff, 1975), and developmental psychopathology (Cicchetti & Cohen, 1995) have such a degree of commonality that Cairns (Cairns, et al., 1996) has proposed incorporating them under the umbrella concept of Developmental Science.

One of the leading proponents of this perspective is Richard M. Lerner, who has made significant contributions at basic theoretical levels (e.g., see references throughout this chapter) and at the policy-level (e.g., Lerner, 2004b) applications of this perspective. The empirical research that Lerner and colleagues have conducted has focused primarily on the natural contextual shifts found in adolescence (e.g., Talwar, Nitz, & Lerner, 1990). For instance, the transition from junior high to high school connotes a significant shift in the contextual demands placed on an adolescent. By

studying the interaction of these contextual shifts with variables such as temperament, it can be shown empirically how these mutual influences not only shape each other, but how they conjointly influence other behavioral outcomes.

Many scientists are already examining social behavior from a developmental contextual perspective. Building on the youth development work of Weiss and her colleagues, Lerner described a Development-In-Context Evaluation (DICE) model for program design and evaluation as a framework for interventions addressing social problems (Ostrom, Lerner, & Freel, 1995). The DICE model explicitly incorporates program designs and policies, as well as evaluation into the nested ecology of behavioral development. Indeed, not only are children and adolescents influenced by program design, implementation, and evaluation activities, they also directly influence those activities in a reciprocal manner. In addition, multiple levels of a developmental system are assessed qualitatively and quantitatively at multiple levels of analysis.

Personality and social psychologist Albert Bandura (1977) proposed his belief that dynamically interactive, person-context developmental models must become incorporated into the theory and research of personality and social psychology. Bandura explains that need for reliance on reciprocal effects in a triadic system of reciprocity among the person or organism, behavior or action, and the environmental or contextual influences. Although Bandura recognizes that current methods that investigate what he calls initial effects, or effects that do not rely on interactional assessment, are important to our understanding of development, he argues that, to understand psychological functioning, our methods must include reciprocal and initial effects. Bandura also believes that, in a reciprocal system, change and context must take a primary focus if the field is to advance.

James Garbarino (1992) explains individual development as a process that occurs in the context of several different levels of influence. Like Lerner and Bandura, Garbarino stresses the importance of being aware of the changing contexts that individuals develop in, the changes over time in the individual's relations to those contexts, and how individuals and contexts continually shape one another. The work of Lerner, Bandura, and Garbarino represents a trend evident across a variety of different researchers who examine individual and social systems problems away from simple cause-and-effect and reductionist models toward an approach to development that incorporates a developmental contextual perspective.

CONCLUSIONS

We have tried to show that, although we envision psychology not as a biological science but as a unique science of its own, the principles of all aspects of biology are pertinent for a full understanding of psychology and especially for the development of behavior. This is reflected in how we define psychology: the biopsychosocial science of behavior. Our discussion attempted to show that biological factors are necessary *participating* but not causative factors in behavior development. Along the way, we took the opportunity to dispel some myths and misunderstandings about the relations of biological factors to behavior: the “true” role of genes; the question of whether there really are minds, and if so, whether they are products of the brain; the value of the overused procedures of brain scans; and the perniciousness of evolutionary psychology, a misguided application of the principles of evolution as they apply to behavioral origins. We concluded our discussion with a treatment of the general topic of development, as it applies in biology in general and in psychology in particular. We earlier made the case that development is crucial to psychology, and that the science can be understood to be a developmental science (Greenberg, Partridge, Mosack, & Lamdin, 2006).

REFERENCES

- Allen, G. E. (2007). A century of evo-devo: The dialectics of analysis and synthesis in twentieth-century life science. In M. D. Laubichler & J. Maienschein (Eds.), *From embryology to evo-devo: A history of developmental evolution* (pp. 123–167). Cambridge, MA: MIT Press.
- Alpi, A., Amrhein, N., Bertl, A., Blatt, A., Blumwald, E., Cervone, F., et al. (2007). Plant neurobiology: No brain, no gain. *Trends in Plant Science*, 12, 135–136.
- Amoyel, M., Cheng, Y., Jiang, Y., & Wilkinson, D. G. (2005). Wnt1 regulates neurogenesis and mediates lateral inhibition of boundary cell specification in the zebrafish hindbrain development. *Development*, 132, 775–785.
- Anderson, P. W. (1972). More is different. *Science*, 177, 393–396.
- Angier, N. (2008, November 11). Scientists and philosophers find that “gene” has a multitude of meanings. *The New York Times*, p. D2.
- Aronson, L. R. (1984). Levels of integration and organization: A re-evaluation of the evolutionary scale. In G. Greenberg & E. Tobach (Eds.), *Evolution of behavior and integrative levels* (pp. 57–81). Hillsdale, NJ: Erlbaum.
- Aronson, L. R., Tobach, E., Rosenblatt, J. R., & Lehrman, D. H. (Eds.). (1972). *Selected writings of T. C. Schneirla*. San Francisco: Freeman.
- Arthur, W. B. (1993). Why do things become more complex. *Scientific American*, 268(5), 144.
- Bailey, P. (1965). *Sigmund the unserene: A tragedy in three acts*. Springfield, IL: Thomas.
- Bak, P. (1996). *How nature works: The science of self-organized criticality*. New York: Springer-Verlag.
- Baltes, P. B., Reuter-Lorenz, P. A., & Rösler, F. (2006). Prologue: Biocultural co-constructivism as a theoretical metascript. In P. B. Baltes, P. A. Reuter-Lorenz, & F. Rösler (Eds.), *Lifespan development and the brain: The perspective of biocultural co-constructivism*. (pp. 3–39). Cambridge: Cambridge University Press.
- Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*, 84, 191–215.
- Bannister, D. (1968). The myth of physiological psychology. *Bulletin of the British Psychological Society*, 21, 229–231.
- Barcellos-Hoff, M. H. (2008). Cancer as an emergent phenomenon in systems radiation biology. *Radiation and Environmental Biophysics*, 47, 33–37.
- Barron, A. B., & Robinson, G. E. (2008). The utility of behavioral models and modules in molecular analyses of social behavior. *Genes, Brain and Behavior*, 7, 257–265.
- Bauchau, V. (2006). Emergence and reductionism: From the game of life to the science of life. In B. Feltz, M. Crommerlinck, & P. Goujon (Eds.), *Self-organization and emergence in life sciences* (pp. 29–40). Dordrecht, The Netherlands: Springer.
- Bennett, M. R., & Hacker, P. M. S. (2003). *Philosophical foundations of neuroscience*. Malden, MA: Blackwell.
- Benno, R. H. (1990). Development of the nervous system: Genetics, epigenetics, and phylogenetics. In M. E. Hahn, J. K. Hewitt, N. D. Henderson, & R. H. Benno (Eds.), *Developmental behavior genetics: Neural, biometrical, and evolutionary approaches* (pp. 113–143). New York: Oxford University Press.
- Berker, E. A. (1985). *Principles of brain function in neuropsychological development of hydrocephalics*. Unpublished doctoral dissertation, University of Michigan, Ann Arbor.
- Bertalanffy, L. von. (1933). *Modern theories of development*. London: Oxford University Press.
- Bickerton, D. (1995). *Language and human behavior*. Seattle, WA: University of Washington Press.
- Blumberg, M. (2005). *Basic instinct: The genesis of behavior*. New York: Thunders Mouth Press.
- Bonner, J. T. (1988). *The evolution of complexity*. Princeton, NJ: Princeton University Press.
- Boorstein, D. J. (1998). *The seekers*. New York: Vintage.
- Breckler, S. J. (2006). The newest age of reductionism. *Monitor on Psychology*, 27(8), 23.
- Bronfenbrenner, U., & Morris, P. A. (2006). The bioecological model of human development. In W. Damon (Series Ed.) & R. M. Lerner (Vol. Ed.), *Theoretical models of human development: Vol. 1, Handbook of child psychology* (6th ed., pp. 793–828). New York: Wiley.
- Brooks, D. (2006, September 17). Is chemistry destiny? *New York Times*, Section 4, p. 14.
- Buller, D. J. (2005). *Adapting minds: Evolutionary psychology and the quest for human nature*. Cambridge, MA: MIT Press.
- Bullock, T. H. (1965/1970). Physiological bases of behavior. In J. A. Moore (Ed.), *Ideas in evolution and behavior*. Garden City, NY: Natural History Press.
- Bunge, M. (1980). *The mind-body problem*. Oxford: Pergamon Press.
- Burian, R. M. (1985). On conceptual change in biology: The case of the gene. In D. J. Depew & B. H. Weber (Eds.), *Evolution at a crossroads: The new biology and the new philosophy of science* (pp. 21–42). Cambridge, MA: MIT Press.
- Buss, D. M. (1999). *Evolutionary psychology: The new science of the mind*. Boston: Allyn and Bacon.
- Buss, D. M. (Ed.). (2005). *The handbook of evolutionary psychology*. Hoboken, NJ: John Wiley.

- Cacioppo, J. T., Bernston, G. G., Sheridan, J. F., & McClintock, B. (2000). Multiple integrative analyses of human behavior: Social neuroscience and the nature of social and biological approaches. *Psychological Bulletin*, *126*, 829–843.
- Cairns, R. B., Elder, G. H., & Costello, E. J. (1996). *Developmental science*. New York: Cambridge University Press.
- Campbell, D. T. (1990). Levels of organization, downward causation, and the selection-theory approach to evolutionary epistemology. In G. Greenberg & E. Tobach (Eds.), *Theories of the evolution of knowing* (pp. 1–17). Hillsdale, NJ: Erlbaum.
- Carroll, S. B. (2001). Chance and necessity: The evolution of morphological complexity and diversity. *Nature*, *409*, 1102–1109.
- Ceci, S., & Williams, W. M. (2009). Darwin 200. Should scientists study race and IQ? Yes: The scientific truth must be pursued. *Nature*, *457*(7231), 788–789.
- Chaisson, E. J. (2001). *Cosmic evolution: The rise of complexity in nature*. Cambridge, MA: Harvard University Press.
- Cicchetti, D., & Cohen, D. J. (1995). *Developmental psychopathology*. New York: Wiley.
- Cole, S. (1983). The hierarchy of the sciences? *American Journal of Sociology*, *89*, 111–139.
- Coltheart, M. (2006). What has functional neuroimaging told us about the mind (so far)? *Cortex*, *42*, 323–331.
- Crick, F. (1970). Central dogma of molecular biology. *Nature*, *227*, 561–563.
- Critchley, M. (1969). Disorders of higher nervous activity: Introductory remarks. In P. J. Vinken & G. W. Bruyn (Eds.), *Handbook of clinical neurology* (Vol. 3). New York: Wiley.
- Darwin, C. (1859). *The origin of species*. London: John Murray.
- Deacon, T. W. (1990). Rethinking mammalian Brain Evolution. *American Zoologist*, *30* 229–705.
- Deacon, T. W. (1997). *The symbolic species: The co-evolution of language and the brain*. New York: W. W. Norton & Co.
- Dean, A. (2000). *Complex life: Nonmodernity and the emergence of cognition and culture*. Aldershot, United Kingdom: Ashgate Publishing.
- Dobbs, D. (2005). Fact or phrenology? *Scientific American Mind*, *16*(1), 24–31.
- Dobzhansky, T. (1973). Nothing in biology makes sense except in the light of evolution. *American Biology Teacher*, *35*, 125–129.
- Dudley, S. A., & File, A. L. (2007). Kin recognition in an annual plant. *Biology Letters*, *3*, 435–438.
- Edelman, G. M. (1992). *Bright air, brilliant fire: On the matter of mind*. New York: Basic Books.
- Edelman, G. M. & Tononi, G. (2000). *A universe of consciousness: How matter becomes imagination*. New York: Basic Books.
- Efron, R. (1990). *The decline and fall of hemispheric specialization*. Hillsdale, NJ: Erlbaum.
- Ehrlich, P. (2000). Human natures: Genes, cultures, and the human prospect. Washington, DC: Island Press.
- Eldredge, N., & Gould, S. J. (1972). Punctuated equilibria: An alternative to phyletic gradualism. In T. J. M. Schopf (Ed.), *Models in paleobiology* (pp. 82–115). San Francisco, CA: Freeman.
- Elman, J. L., Bates, E. A., Johnson, M. H., Karmiloff-Smith, A., Parisi, D., & Plunkett, K. (1996). *Rethinking innateness: A connectionist perspective on development*. Cambridge, MA: MIT Press.
- Fausto-Sterling, A. (1985). Myths of gender: Biological theories about women and men. New York: Basic Books.
- Feibleman, J. K. (1954). Theory of integrative levels. *British Journal for the Philosophy of Science*, *5*, 59–66.
- Finkel, D., Wille, D. E., & Matheny A. P. (1998). Preliminary results from a twin study of infant-caregiver attachment. *Behavior Genetics*, *28*(1), 1–8.
- Fodor, J. (1999, September 30). Let your brain alone. *London Review of Books*, p. 21.
- Ford, D. H., & Lerner, R. M. (1992). *Developmental systems theory: An integrative approach*. Newbury Park, CA: Sage Publications.
- Fowler, J. H., Dawes, C. T., & Christakis, N. A. (2009). Model of genetic variation in human social networks. *Proceedings of the National Academy of Science*, *106*(6), 1720–1724.
- Freeman, W. J. (1991). The physiology of perception. *Scientific American*, *264*(2), 78–85.
- Freeman, W. J. (1992). Tutorial in neurobiology: From single neurons to brain chaos. *International Journal of Bifurcation and Chaos*, *2*, 451–482.
- Freeman, W. J. (2001). Three centuries of category errors in studies of the neural basis of consciousness and intentionality. In W. Sulis & I. Trofimova (Eds.), *Nonlinear dynamics in the life and social sciences* (pp. 275–285). Amsterdam: IOS Press.
- Friedman, A., & Polson, M. C. (1981). Hemispheres as independent resource systems: Limited-capacity processing and cerebral specialization. *Journal of Experimental Psychology: Human Perception and Performance*, *7*, 1031–1058.
- Futuyma, D. J. (1998). *Evolutionary biology* (3rd ed.). Sunderland, MA: Sinauer Associates Inc.
- Gannon, P. J., Holloway, R. L., Broadfield, D. C., & Braun, A. R. (1998). Asymmetry of chimpanzee planum temporale: Humanlike brain pattern of Wernicke's language area homolog. *Science*, *279*, 222–226.
- Garbarino, J. (1992). *Children and families in the social environment*. New York: Aldine.
- Gazzaniga, M. S. (1967). The split-brain in man. *Scientific American*, *217*, 24–29.
- Gazzaniga, M. S. (1983). Right hemisphere language following brain bisection: A 20-year perspective. *American Psychologist*, *38*, 525–537.
- Gazzaniga, M. S. (1984). Right hemisphere language: Remaining problems. *American Psychologist*, *39*, 1494–1496.
- Gallup, G. G., Frederick, M. J., & Pipitone, R. N. (2008). Morphology and behavior: Phrenology revisited. *Review of General Psychology*, *12*, 297–304.
- Geard, N., & Wiles, J. (2005). A gene network model for developing cell lineages. *Artificial Life*, *11*(1–2), 249–268.
- Gibson, J. J. (1966). *The ecological approach to visual perception*. Mahwah, NJ: Lawrence Erlbaum.
- Gilbert, S. F., & Sarkar, S. (2000). Embracing complexity: Organicism for the 21st century. *Developmental Dynamics*, *219*, 1–9.
- Goldfield, E. C. (1995). *Emergent forms: Origins and early development of human action and perception*. New York: Oxford University Press.
- Goodwin, B. (2009). Pan-sentience. In J. Brockman (Ed.), *What have you changed your mind about? Today's leading minds rethink everything* (pp. 2–4). New York: Harper.
- Gottlieb, G. (1984). Evolutionary trends and evolutionary origins: Relevance to theory in comparative psychology. *Psychological Review*, *91*, 448–456.
- Gottlieb, G. (1992). *Individual development and evolution: The genesis of novel behavior*. New York: Oxford University Press.
- Gottlieb, G. (1998). Normally occurring environmental and behavioral influences on gene activity: From central dogma to probabilistic epigenesis. *Psychological Review*, *105*, 792–802.
- Gottlieb, G. (2001). A developmental psychobiological systems view: Early formulation and current status. In S. Oyama, P. E. Griffiths, & R. D. Gray (Eds.), *Cycles of contingency: Developmental systems and evolution* (pp. 41–54). Cambridge, MA: MIT Press.

- Gottlieb, G. (2004). Normally occurring environmental and behavioral influences on gene activity: From central dogma to probabilistic epigenesis. In C. G. Coll, E. L. Bearer, & R. M. Lerner (Eds.), *Nature and nurture: The complex interplay of genetic and environmental influences on human behavior and development* (pp. 85–106). Mahwah, NJ: Erlbaum.
- Gottlieb, G. (2006). Developmental neurobehavioral genetics: Development as explanation. In B. C. Jones & P. N. Mormede (Eds.), *Neurobehavioral genetics: Methods and applications* (2nd ed., pp. 17–27). Boca Raton, FL: CRC Press.
- Gould, S. J. (1988). On replacing the idea of progress with an operational definition of directionality. In M. H. Nitecki (Ed.), *Evolutionary progress* (pp. 319–338). Chicago: University of Chicago Press.
- Gould, S. J. (1997a). Darwinian fundamentalism. *New York Review of Books*, 44(10), 34–37.
- Gould, S. J. (1997b). *Full house: The spread of excellence from Plato to Darwin*. New York: Three Rivers Press.
- Gould, S. J., & Eldredge, N. (1993). Punctuated equilibrium comes of age. *Nature*, 366, 223–227.
- Greenberg, G. (1972). The effects of ambient temperature and population density on aggression in two strains of mice, *Mus musculus*. *Behaviour*, 42, 119–131.
- Greenberg, G. (1983). Psychology without the brain. *Psychological Record*, 33, 49–58.
- Greenberg, G. (1995). Anagenetic theory in comparative psychology. *International Journal of Comparative Psychology*, 8, 31–41.
- Greenberg, G., & Haraway, M. H. (2002). *Principles of comparative psychology*. Boston, MA: Allyn & Bacon.
- Greenberg, G., Partridge, T., & Ablah, E. (2007). The significance of the concept of emergence for comparative psychology. In D. Washburn (Ed.), *Primate perspectives on behavior and cognition* (pp. 81–98). Washington, DC: American Psychological Association.
- Greenberg, G., Partridge, T., Mosack, V., & Lambin, C. (2006). Psychology is a developmental science. *International Journal of Comparative Psychology*, 19, 185–205.
- Greenberg, G., Partridge, T., Weiss, E., & Haraway, M. M. (1998). Integrative levels, the brain, and the emergence of complex behavior. *Review of General Psychology*, 3, 168–187.
- Greenberg, G., Partridge, T., Weiss, E., & Pisula, W. (2004). Comparative psychology: A new perspective for the 21st century. Up the spiral staircase. *Developmental Psychobiology*, 44, 1–15.
- Griffiths, A. J. F., Wessler, S. R., Lewontin, R. C., Gelbart, W. M., Suzuli, D. T., & Miller, J. H. (2005). *Introduction to genetic analysis* (8th ed.). New York: W. H. Freeman.
- Griffiths, P. E., & Gray, R. D. (2005). Discussion: Three ways to misunderstand developmental systems theory. *Biology and Philosophy*, 20, 417–425.
- Griffiths, T. D., & Warren, J. D. (2002). The planum temporale as a computational hub. *Trends in Neuroscience*, 25, 348–353.
- Haraway, M. H. & Maples, E. (1998). Species-typical behavior. In G. Greenberg & M. H. Haraway (Eds.), *Comparative psychology: A handbook*. New York: Garland.
- Hardcastle, V. G., & Stewart, C. M. (2002). What do brain data really show? *Philosophy of Science*, 69, S72–S82.
- Hardin, G. (1956). Meaninglessness of the word protoplasm. *Scientific Monthly*, 82(3), 112–120.
- Harper, L. V. (in press). Trans-generational epigenetic inheritance. In K. Hood, C. Halpern, G. Greenberg, & R. Lerner (Eds.), *Handbook of developmental science, behavior and genetics*. Malden, MA: Blackwell.
- Hebb, D. O. (1953). Heredity and environment in mammalian behavior. *British Journal of Animal Behaviour*, 1, 43–47.
- Heinrichs, R. W. (1993). Schizophrenia and the brain. *American Psychologist*, 48, 221–233.
- Heyes, C. M. (1998). Theory of mind in nonhuman primates. *Behavioral and Brain Sciences*, 21, 101–148.
- Holland, J. H. (1995). *Hidden order: How adaptation builds complexity*. Reading, MA: Addison-Wesley.
- Honeycutt, H. (2006). Studying evolution in action: Foundations for a transgenerational comparative psychology. *International Journal of Comparative Psychology*, 19, 170–184.
- Hull, D. (1972). Reduction in genetics—biology or philosophy? *Philosophy of Science*, 39, 491–499.
- Ingold, T. (2000). Evolving skills. In H. Rose & S. Rose (Eds.), *Alas poor Darwin: Arguments against evolutionary psychology* (pp. 273–297). New York: Harmony Books.
- Jarvilehto, T. (1998). The theory of theorganism-environment system: I. Description of the theory. *Integrative Psychological and Behavioral Science*, 33(4), 321–334.
- Jaynes, J. (1973). A long way from genes to behavior and molecules to man. [Review of *Selected writings of T. C. Schmeirla*]. *Contemporary Psychology*, 18, 611–613.
- Jerison, H. (1973). *Evolution of the brain and intelligence*. New York: Academic Press.
- Jerison, H. J. (1994). Evolution of the brain. In D. W. Zaidel (Ed.), *Neuropsychology. Handbook of perception and cognition* (2nd ed., pp. 53–82). San Diego: Academic Press.
- Joseph, J. (in press). Genetic research in psychiatry and psychology: A critical overview. In K. E. Hood, C. T. Halpern, G. Greenberg, & R. M. Lerner (Eds.), *Handbook of developmental science, behavior, and genetics*. Malden, MA: Blackwell.
- Joshi, M., & Tyndale, R. F. (2006). Regional and cellular distribution of CYP2E1 in monkey brain and its induction by chronic nicotine. *Neuropharmacology*, 50, 568–575.
- Kalat, J. W. (2009). *Biological psychology* (10th ed.). Belmont, CA: Wadsworth.
- Kantor, J. R. (1924). *Principles of psychology* (Vol. 1). Bloomington, IN: Principia Press.
- Kantor, J. R. (1926). *Principles of psychology* (Vol. 2). Bloomington, IN: Principia Press.
- Kantor, J. R. (1959). *Interbehavioral psychology* (2nd ed.). Chicago: Principia Press.
- Kaplan, G., & Rogers, L. J. (2003). *Gene worship: Moving beyond the nature/nurture debate over genes, brain, and gender*. New York: Other Press.
- Kauffman, S. (2007). Beyond reductionism: Reinventing the sacred. *Zygon*, 42, 903–914.
- Kaye, H. L. (1992, Spring). Are we the sum of our genes? *Wilson Quarterly*, 16, 77–84.
- Keller, E. F. (2000). *The century of the gene*. Cambridge, MA: Harvard University Press.
- Keller, E. F. (2002). *Making sense of life: Explaining biological development with models, metaphors, and machines*. Cambridge, MA: Harvard University Press.
- Keller, E. F. (2005). DDS: Dynamics of developmental systems. *Biology and Philosophy*, 20, 409–416.
- Killackey, H. P. (1990). Neocortical expansion: An attempt toward relating phylogeny and ontogeny. *Journal of Cognitive Neuroscience*, 2, 1–17.
- Knoblich, J. A. (2001). Asymmetric cell division during animal development. *Nature Reviews Molecular Cell Biology*, 2, 11–20.
- Ko, E. P., Yomo, T., & Urabe, I. (1994). Dynamic clustering of bacterial populations. *Physica D*, 75(1–3), 81–88.
- Koch, C. & Laurent, G. (1999). Complexity and the nervous system. *Science*, 284, 96–98.

- Krasny, M. (1997). Stephen Jay Gould. *Mother Jones*, 22(1), 60–63.
- Kugler, P. N., & Turvey, M. T. (1987). *Information, natural law and the self-assembly of rhythmic movement*. Mahwah, NJ: Lawrence Erlbaum.
- Kuo, Z. Y. (1967). *The dynamics of behavior development*. New York: Random House.
- Kuo, Z. Y. (1970). The need for coordinated efforts in developmental studies. In L. R. Aronson, E. Tobach, D. S. Lehrman, & J. S. Rosenblatt (Eds.), *Development and evolution of behavior: Essays in memory of T. C. Schneirla* (pp. 182–193). San Francisco, CA: W. H. Freeman.
- Leahey, T. H. (2000). *A history of psychology: Main currents in psychological thought*. Upper Saddle River, NJ: Prentice Hall.
- Lerner, R. M. (1984). *On the nature of human plasticity*. Cambridge: Cambridge University Press.
- Lerner, R. M. (1998). Developmental contextualism. In G. Greenberg & M. M. Haraway (Eds.), *Comparative psychology: A handbook* (pp. 88–97). New York: Garland.
- Lerner, R. M. (2002). *Concepts and theories of development* (3rd ed.). Mahwah, NJ: Erlbaum.
- Lerner, R. M. (2004a). Genes and the promotion of positive human development: Hereditarian versus developmental systems perspectives. In C. G. Coll, E. L. Bearer, & R. M. Lerner (Eds.), *Nature and nurture: The complex interplay of genetic and environmental influences on human behavior and development* (pp. 1–33). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
- Lerner, R. M. (2004b). *Liberty: Thriving and civic engagement among America's youth*. Thousand Oaks, CA: SAGE.
- Lerner, R. M. (2006). Developmental science, developmental systems, and contemporary theories of human development. In W. Damon (Series Ed.) & R. M. Lerner (Vol. Ed.), *Theoretical models of human development: Vol. 1, Handbook of child psychology* (pp. 1–17, 6th ed.). New York: Wiley.
- Lerner, R. M. & Busch-Rossnagle, N. A. (Eds.). (1981). *Individuals as producers of their development: A life-span perspective*. New York: Academic Press.
- Lerner, R. M., & Overton, W. F. (2008). Exemplifying the integrations of the relational developmental system: Synthesizing theory, research, and application to promote positive development and social justice. *Journal of Adolescent Research*, 23, 245–255.
- Lewin, R. (1980). Is your brain really necessary? *Science*, 210, 1232–1234.
- Lewin, R. (1992). *Complexity: Life at the edge of chaos*. New York: Macmillan.
- Lewontin, R. (1997). Billions and billions of demons. *New York Review of Books*, 44(1), 28–32.
- Lewontin, R. (2000). *It ain't necessarily so: The dream of the Human Genome and other illusions*. New York: New York Review Books.
- Lickliter, R., & Honeycutt, H. (2003). Developmental dynamics: Toward a biologically plausible evolutionary psychology. *Psychological Bulletin*, 129, 819–835.
- Lieberman, P. (1998). *Eve spoke*. New York: Norton.
- Linden, D. J. (2007). *The accidental mind*. Cambridge, MA: Harvard University Press.
- Loftus, E. F., & Loftus, G. R. (1980). On the permanence of stored information in the brain. *American Psychologist*, 35, 409–420.
- Lorber, J. (1983). Is your brain rally necessary? In D. Voth (Ed.), *Hydrocephalus im frühen Kindesalter: Fortschritte der Grundlagenforschung, Diagnostik und Therapie* (pp. 2–14). Stuttgart, Germany: Ferdinand Enke Verlag.
- Lovelock, J. E. (1979). *Gaia, a new look at life on earth*. New York: Oxford University Press.
- Macmillan, M. (2008). Phineas Gage: Unravelling [sic] the myth. *The Psychologist*, 21(9), 828–831.
- Magnusson, D. (1995). Individual development: A holistic integrated model. In P. Moen, G. H. Elder, & K. Luscher (Eds.), *Examining lives in context: Perspectives on the ecology of human development* (pp. 19–60). Washington, DC: American Psychological Association.
- Maier, N. R. F., & Schneirla, T. C. (1964). *Principles of animal psychology (Enlarged edition)*. New York: Dover. (Original work published 1935)
- Malaiyandi, V., Sellers, E. M., & Tyndale, R. F. (2005). Implications of CYP2A6 genetic variation for smoking behaviors and nicotine dependence. *Perspectives in Clinical Pharmacology*, 77, 145–158.
- Manger, P. R., Cort, J., Ebrahim, N., Goodman, A., Henning, J., Karolia, M., et al. (2008). Is 21st century neuroscience too focussed on the rat/mouse model of brain function and dysfunction? *Frontiers in Neuroanatomy*, 2, 1–7.
- Marshall, P. J. (2009). Relating psychology and neuroscience. *Perspectives on Psychological Science*, 4, 113–125.
- Matsuzawa, T. (1998). Chimpanzee behavior: A comparative cognitive perspective. In G. Greenberg and M. M. Haraway (Eds.), *Comparative psychology: A handbook* (pp. 360–375). New York: Garland.
- Maynard Smith, J. (1970). Time in the evolutionary process. *Studium Generale*, 23, 266–272.
- Mayr, E. (1970). *Populations, species, and evolution*. Cambridge, MA: Harvard University Press.
- Mayr, E. (1979). Evolution. *Scientific American*, 239(3), 46–55.
- Mayr, E. (1985). How biology differs from the physical sciences. In D. J. Depew & B. H. Weber (Eds.), *Evolution at a crossroads: The new biology and the new philosophy of science* (pp. 44–63). Cambridge, MA: MIT Press.
- Mayr, E. & Provine, W. B. (1980). *The evolutionary synthesis: Perspectives on the unification of biology*. Cambridge, MA: Harvard University Press.
- McCabe D. P., & Castel, A. D. (2007). Seeing is believing: The effect of brain images on judgements of scientific reasoning. *Cognition*, 107, 343–352.
- Medawar, P. (1974). A geometric model of reduction and emergence. In F. C. Ayala & T. Dobzhansky (Eds.), *Studies in the philosophy of biology* (pp. 57–63). Los Angeles: University of California Press.
- Michel, G. F. (1981). Right handedness: A consequence of infant supine head orientation preference? *Science*, 212, 685–687.
- Michel, G. F. (in press). The meaning of the concept of experience in behavioral development. In K. E. Hood, C. T. Halpern, G. Greenberg, & R. M. Lerner (Eds.), *Handbook of developmental science, behavior, and genetics*. Malden, MA: Blackwell.
- Michel, G. F., & Goodwin, R. (1979). Intrauterine birth position predicts newborn supine head position preference. *Infant Behavior and Development*, 2, 29–38.
- Michel, G. F., & Moore, C. L. (1995). *Developmental psychobiology*. Cambridge, MA: MIT Press.
- Miconi, T. (2008). Evolution and complexity: The double-edged sword. *Artificial Life*, 14, 325–344.
- Miller, G. (2007). Six memos for evo-devo. In M. D. Laubichler & J. Maienschein (Eds.), *From embryology to evo-devo: A history of developmental evolution* (pp. 499–524). Cambridge, MA: MIT Press.
- Moffat, S. D., Kennedy K. M., Rodrigue, K. M., & Raz, N. (2007). Extrahippocampal contributions to age differences in human spatial navigation. *Cerebral Cortex*, 17(6), 1274–1282.
- Molenaar, P. C. M. (2007). Psychological methodology will change profoundly due to the necessity to focus on intra-individual

- variation. *Integrative Psychological and Behavioral Science*, 41(1), 1932–4502.
- Montagu, A. (1962). Our changing conception of human nature. In *The humanization of man* (pp. 15–34). New York: Grove Press. (Reprinted from *Impact* [UNESCO], 1952, 3, 219–232)
- Montagu, M. (1972). Sociogenic brain damage. *American Anthropologist*, 74, 1045–1061.
- Morgan, C. L. (1923). *Emergent evolution: The Gifford lectures*. London: Williams and Norgate.
- Moss, L. (2003). *What genes can't do*. Cambridge, MA: MIT Press.
- Myers, J. J. (1984). Right hemisphere language: Science or fiction? *American Psychologist*, 39, 315–320.
- Needham, J. (1929). *The skeptical biologist*. London: Chatto.
- Nelkin, D. (1993). The social power of genetic information. In D. Kevles and L. Hood (Eds.), *The code of codes: Scientific and social issues in the human genome project* (pp. 177–190). Cambridge, MA: Harvard University Press.
- Nesselroade, J. R. (2006). Quantitative modeling in adult development and aging: Reflections and projections. In C. S. Bergman & S. M. Boker (Eds.), *Methodological issues in aging* (pp. 1–18). Mahwah, NJ: Routledge.
- Neumann-Held, E. M. (2001). Let's talk about genes: The process molecular gene concept and its context. In S. Oyama, P. E. Griffiths, & R. D. Gray (Eds.), *Cycles of contingency: Developmental systems and evolution* (pp. 69–84). Cambridge, MA: MIT Press.
- Nieuwkoop, P. D., Johnen, A. G., & Albers, B. (1985). *The epigenetic nature of early chordate development: Inductive interaction and competence*. Cambridge, England: Cambridge University Press.
- Niiniluoto, I. (1994). Scientific realism and the problem of consciousness. In A. Revonsuo & M. Kamppinen (Eds.), *Consciousness in philosophy and cognitive neuroscience* (pp. 33–34). Hillsdale, NJ: Erlbaum.
- Nishida, T. (1986). Learning and cultural transmission in nonhuman primates. *Folia Primatologica*, 12, 273–283.
- Nitecki, M. H. (1988). *Evolutionary progress*. Chicago: University of Chicago Press.
- Noë, A. (2008). The problem of consciousness: A talk with Alva Noë. *Edge: The third culture*. Retrieved December 26, 2008, from http://www.edge.org/3rd_culture/noe08/noe08_index.html#rc.
- Novikoff, A. (1945). The concept of integrative levels and biology. *Science*, 101, 209–215.
- Olson, E. C. (1976). Rates of evolution of the nervous system and behavior. In R. B. Masterton, W. Hodos, & H. Jerison (Eds.), *Evolution, brain and behavior: Persistent problems* (pp. 47–77). Hillsdale, NJ: Erlbaum.
- Ostrom, C. W., Lerner, R. M., & Freel, M. A. (1995). Building the capacity of youth and families through university-community collaboration. *Journal of Adolescent Research*, 10, 427–448.
- Overton, W. F. (1975). General systems, structure and development. In K. Riegel & G. Rosenwald (Eds.), *Structure and transformation: Developmental aspects* (pp. 61–81). New York: Wiley Interscience.
- Overton, W. F. (2006). Developmental psychology: Philosophy, concepts, methodology. In W. Damon (Series Ed.) & R. M. Lerner (Vol. Ed.), *Theoretical models of human development: Vol. 1, Handbook of child psychology* (6th ed., pp. 18–88). New York: Wiley.
- Overton, W. F., Mueller, U., & Newman, J. L. (Eds.). (2007). *Developmental perspective on embodiment and consciousness*. Hillsdale, NJ: Erlbaum Associates.
- Overton, W. F., & Reese, H. W. (1973). Models of development: Methodological implications. In J. R. Nesselroade & H. W. Reese (Eds.), *Life-span developmental psychology: Methodological issues* (pp. 65–86). New York: Academic Press.
- Oyama, S. (1985). *The ontogeny of information: Developmental systems and evolution*. Cambridge: Cambridge University Press.
- Oyama, S. (2000). *Evolution's eye: A systems view of the biology-culture divide*. Durham, NC: Duke University Press.
- Page, M. P. A. (2006). What can't functional neuroimaging tell the cognitive psychologist? *Cortex*, 42, 428–443.
- Panskepp, J., & Panskepp, J. B. (2000). The seven sins of evolutionary psychology. *Evolution and Cognition*, 6, 108–131.
- Pantin, C. F. A. (1951). Organic design. *The Advancement of Science*, 30, 138–150.
- Partridge, T., & Greenberg, G. (in press). Contemporary ideas in physics and biology in Gottlieb's psychology. In K. Hood, C. Halpern, G. Greenberg, & R. Lerner (Eds.), *Handbook of developmental science, behavior and genetics*. Malden, MA: Blackwell.
- Penfield, W. (1958a). Some mechanisms of consciousness discovered during electrical stimulation of the brain. *Proceedings of the National Academy of Sciences*, 44(2), 51–66.
- Penfield, W. (1958b). Hippocratic preamble: The brain and intelligence. In F. N. L. Poynter (Ed.), *The brain and its functions: An Anglo-American symposium* (pp. 1–4). Oxford: Blackwell Scientific Publications.
- Penfield, W., & Perot, P. (1963). The brain's record of auditory and visual experience: A final summary and discussion. *Brain*, 86, 595–697.
- Pinker, S. (1999). *How the mind works*. New York: W.W. Norton.
- Pinker, S. (2002). *The blank slate: The modern denial of human nature*. New York: Penguin.
- Plotkin, H. C. (1983). The functions of learning and cross-species comparisons. In G. C. L. Davey (Ed.), *Animal models of human behavior* (pp. 117–134). New York: Wiley.
- Plotnik, R., & Mollenauer, S. (1978). *Brain and behavior*. San Francisco: Canfield Press.
- Pribram, K. (Ed.). (1993). *Rethinking neural networks: Quantum fields and biological data*. Mahwah, NJ: Lawrence Erlbaum.
- Pribram, K. (Ed.). (1996). *Learning as self-organization*. Mahwah, NJ: Lawrence Erlbaum.
- Pronko, N. H. (1973). *Panorama of psychology* (2nd ed.). Monterey, CA: Brooks/Cole.
- Pronko, N. H. (1980). *Psychology from the standpoint of an interbehaviorist*. Belmont, CA: Wadsworth.
- Pronko, N. H. (1988). "Soul": The transformation of "soul" to "mind" and "mind" to "brain." In N. H. Pronko (Ed.), *From AI to Zeitgeist: A philosophical guide for the skeptical psychologist* (pp. 188–189). New York: Greenwood Press.
- Reid, R. G. B. (2007). *Biological emergences: Evolution by natural experiment*. Cambridge, MA: MIT Press.
- Reinhart, J. B., & Drash, A. L. (1969). Psychosocial dwarfism: Environmentally induced recovery. *Psychosomatic Medicine*, 31, 165–172.
- Reise, W. (1958). Descartes' ideas of brain function. In F. N. L. Poynter (Ed.), *The brain and its functions: An Anglo-American symposium* (pp. 115–134). Oxford: Blackwell Scientific Publications.
- Renthal, W., & Nestler, E. J. (2008). Epigenetic mechanisms is drug addiction. *Trends in Molecular Medicine*, 14, 341–350.
- Risch, N., Herrell, R., Lehner, T., Liang, K-Y., Eaves, L., Hoh, J., et al. (2009). Interaction between the serotonin transporter gene (5-HTTLPR), stressful life events, and risk of depression: A meta-analysis. *Journal of the American Medical Association*, 301(23), 2462–2470.
- Robert, J. S. (2004). *Embryology, epigenesis, and evolution: Taking development seriously*. Cambridge: Cambridge University Press.
- Robert, J. S., Hall, B. K., & Olson, W. M. (2001). Bridging the gap between developmental systems theory and evolutionary developmental biology. *BioEssays*, 23, 954–962.

- Robinson, G. E., Fernald, R. D., & Clayton, D. F. (2008). Genes and social behavior. *Science*, 322, 896–900.
- Rogers, L. (1999). *Sexing the brain*. London: Weidenfeld & Nicolson.
- Rogers, L. J. (In press). Interactive contributions of genes, hormones and early experience to behavioural development discussed in a social and ecological context. In K. E. Hood, C. T. Halpern, G. Greenberg & R. M. Lerner (Eds.), *Handbook of developmental science, behavior and genetics: Honoring the work of Gilbert Gottlieb*. Malden, MA: Wiley-Blackwell.
- Rose, S. (1989). *The conscious brain (revised ed)*. New York: Paragon House.
- Rose, S. (2009). Darwin 200: Should scientists study race and IQ? No: Science and society do not benefit. *Nature*, 457(7231), 786–789.
- Roskies, A. L. (2007). Are neuroimages like photographs of the brain? *Philosophy of Science*, 74, 860–872.
- Rudel, D., & Sommer, R. J. (2003). The evolution of developmental mechanisms. *Developmental Biology*, 264, 15–37.
- Rumbaugh, D. M. & Pate, J. L. (1984). The evolution of cognition in primates: A comparative perspective. In H. L. Roitblatt, T. G. Bever & H. S. Terrace (Eds.), *Animal cognition* (pp. 569–587). Hillsdale, NJ: Erlbaum.
- Ruse, M. (2006). Forty years a philosopher of biology: Why evo-devo makes me still excited about my subject. *Biological Theory*, 1, 35–37.
- Sameroff, A. (1975). Transactional models in early social relations. *Human Development*, 18(1–2), 65–79.
- Saunders, P. T., & Ho, M. W. (1976). On the increase in complexity in evolution. *Journal of Theoretical Biology*, 63, 375–384.
- Saunders, P. T., & Ho, M. W. (1981). On the increase in complexity in evolution. II. The relativity of complexity and the principle of minimum increase. *Journal of Theoretical Biology*, 90, 515–530.
- Savage-Rumbaugh, S., Shanker, S. G., & Taylor, T. J. (1998). *Apes, language, and the human mind*. New York: Oxford University Press.
- Schneirla, T. C. (1949). Levels in the psychological capacities of animals. In R. W. Sellars, V. J. McGill, & M. Farber (Eds.), *Philosophy for the future* (pp. 243–286). New York: Macmillan.
- Schneirla, T. C. (1957). The concept of development in comparative psychology. In D. B. Harris (Ed.), *The concept of development: An issue in the study of human behavior* (pp. 78–108). Minneapolis: University of Minnesota Press.
- Schneirla, T. C. (1972). The concept of development in comparative psychology. In Aronson, L. R., Tobach, E., Rosenblatt, J. S., & Lehrman, D. S. (Eds.), (1972). *Selected writings of T. C. Schneirla* (pp. 259–294). San Francisco: Freeman. (Reprinted from *The concept of development*, pp. 78–108, D. B. Harris, Ed., 1957, Minneapolis: University of Minnesota Press)
- Seay, B. & Gottfried, N. (1978). *The development of behavior: A synthesis of developmental and comparative psychology*. Boston: Houghton Mifflin Co.
- Sherrington, C. S. (1906/1947). *The integrative action of the nervous system* (2nd ed.). New Haven, CT: Yale University Press.
- Sherrington, C. (1951/1964). *Man on his nature* (Rev. ed.). New York: Mentor.
- Singh, S. (2005). *Big bang*. New York: Harper.
- Sirotin, Y. B., & Das, A. (2009). Anticipatory haemodynamic signals in sensory cortex not predicted by local neuronal activity. *Nature*, 457, 475–480.
- Skinner, B. F. (1974). *About behaviorism*. New York: Knopf.
- Skinner, B. F. (1977). Why I am not a cognitive psychologist. *Behaviorism*, 5, 1–10.
- Smith, A., & Sugar, O. (1975). Development of above normal language and intelligence 21 years after left hemispherectomy. *Neurology*, 25, 813.
- Smith, E. (2008). Before Darwin: How the earth went from lifeless to life. *The Scientist*, 22(6), 32–xx.
- Smith, L. B., & Thelen, E. (2003). Development as a dynamic system. *Trends in Cognitive Science*, 7, 343–348.
- Solé, R., & Goodwin, B. (2000). *Signs of life: How complexity pervades biology*. New York: Basic Books.
- Sperry, R. W. (1982). Some effects of disconnecting the cerebral hemispheres. *Science*, 217, 1223–1226.
- Sperry, R. W. (1991). In defense of mentalism and emergent interaction. *Journal of Mind and Behavior*, 12, 221–245.
- Sperry, R. W. (1993). The impact and promise of the cognitive revolution. *American Psychologist*, 48, 878–885.
- Stoltenberg, S. F., & Hirsch, J. (1998). Behavior-genetic analysis. In G. Greenberg & M. M. Haraway (Eds.), *Comparative psychology: A handbook* (pp. 226–235). New York: Garland.
- Strohman, R. C. (1997). The coming Kuhnian revolution in biology. *Nature Biotechnology*, 15, 194–200.
- Talwar, R., Nitz, K., & Lerner, R. M. (1990). Relations among early adolescent temperament, parent and peer demands, and adjustment: A test of the goodness of fit model. *Journal of Adolescence*, 13(3), 279–298.
- Thelen, E. (1989). Self-organization in developmental processes: Can systems approaches work? In M. R. Gunnar & E. Thelen (Eds.), *Systems and development: The Minnesota symposium in child psychology*, 22, 77–117.
- Thelen, E. (1990). Coupling perception and action in development of skill: A dynamic approach. In H. Bloch & B. Bertenthal (Eds.), *Sensory motor organizations and development in infancy and early childhood* (pp. 39–56). Dordrecht, The Netherlands: Kluwer.
- Thelen, E. (2004). Motor development as a foundation and future of developmental psychology. In W. W. Hartup & R. K. Silbereisen (Eds.), *Growing points in developmental science* (pp. 1–23). New York: Psychology Press.
- Thiessen, D. & Villarriell, R. (1998). Allometry and comparative psychology: Technique and theory. In G. Greenberg & M. M. Haraway (Eds.), *Comparative psychology: A handbook* (pp. 51–65). New York: Garland.
- Thomas, R. (2007). Recurring errors among recent history of psychology textbooks. *American Journal of Psychology*, 120, 477–495.
- Thornton, E. M. (1984). *The Freudian fallacy: An alternative view of Freudian theory*. Garden City, NY: Doubleday.
- Tobach, E., & Schneirla, T. C. (1968). The biopsychology of social behavior of animals. In R. E. Cook & S. Levin (Eds.), *The biological basis of pediatric practice* (pp. 68–82). New York: McGraw-Hill.
- Tononi, G., & Edelman, G. M. (1998). Consciousness and complexity. *Science*, 282, 1846–1851.
- Toobey, J., & Cosmides, L. (1995). Forward. In S. Baron-Cohen (Ed.), *Mind-blindness: An essay on autism and theory of mind* (pp. xi–xviii). Cambridge, MA: MIT Press.
- University of Sheffield. (n.d.). The AHRC *Innateness and the Structure of the Mind* Project. Retrieved from <http://www.philosophy.dept.shef.ac.uk/AHRB-Project>. Accessed January 2, 2010.
- Uttal, W. R. (2001). *The new phrenology: The limits of localizing cognitive processes in the brain*. Cambridge, MA: MIT Press.
- Uttal, W. R. (2005). *Neural theories of mind: Why the mind-brain problem may never be solved*. Mahwah, NJ: Erlbaum.
- Valenstein, E. S. (1973). *Brain control*. New York: John Wiley.
- Valenstein, E. S., Cox, V. C., & Kakolewski, J. W. (1970). Reexamination of the role of the hypothalamus in motivation. *Psychological Review*, 77, 16–31.

148 Biology, Evolution, and Psychological Development

- Venter, J. C., Adams, M. D., Myers, E. W., Li, P. W., Mural, R. J., Sutton, G. G., et al. (2001). The sequence of the human genome. *Science*, *291*(5507), 1304–1351.
- Vogel, S. (1998). Locomotor behavior and physical reality. In G. Greenberg & M. M. Haraway (Eds.), *Comparative psychology: A handbook* (pp. 713–719). New York: Garland.
- von Uexküll, J. (1957). A stroll through the world of animals and men. In C. H. Schiller (Ed.), *Instinctive behavior* (pp. 5–80). New York: International Universities Press.
- Vrba, E. S., & Eldredge, N. (1984). Individuals, hierarchies and processes: Towards a more complete evolutionary theory. *Paleobiology*, *10*, 146–171.
- Vul, E., Harris, C., Winkielman, P., & Pashler, H. (2009). Puzzlingly high correlations in fMRI studies of emotion, personality, and social cognition. *Perspectives on Psychological Science*, *4*, 274–290.
- Waddington, C. H. 1969. "The Theory of Evolution Today." In A. Koestler and S. Smythies (eds.), *Beyond Reductionism* (pp. 357–374). London: Hutchinson.
- Watson, J. D., & Crick, F. H. C. (1953). A structure for deoxyribose nucleic acid. *Nature*, *171*, 737–738.
- Weber, B. H. (2007). Emergence of life. *Zygon*, *42*, 837–856.
- Weisberg, D. S., Keil, F. C., Goodstein, J., Rawson, E., & Gray, J. R. (2008). The allure of neuroscience explanations. *Journal of Cognitive Neuroscience*, *20*, 470–477.
- Willems, R. E., & Hagoort, P. (2009). Broca's region: Battles are not won by ignoring half of the facts. *Trends in Cognitive Neuroscience*, *13*(3), 101.
- Woodger, J. H. (1929). *Biological principles: A critical study*. London: Routledge and Kegan Paul.
- Yamamoto, Y., & Jeffery, W. R. (2000). Central role for the lens in cave fish eye degeneration. *Science*, *289*, 631–633.
- Yarczower, M. (1984). Behavior and evolutionary progress: Anagenesis, grades, and evolutionary scales. In G. Greenberg & E. Tobach (Eds.), *Behavioral evolution and integrative levels: The T. C. Schneirla Conference Series* (Vol. 1, pp. 105–120). Hillsdale, NJ: Erlbaum.
- Zimmer, C. (2004). *Soul made flesh: The discovery of the brain—and how it changed the world*. New York: Free Press.