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The Second Law of Thermodynamics Is the First Law of Psychology: Evolutionary Developmental Psychology and the Theory Of Tandem, Coordinated Inheritances: Comment on Lickliter and Honeycutt (2003)

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Organisms inherit a set of environmental regularities as well as genes, and these two inheritances repeatedly encounter each other across generations. This repetition drives natural selection to coordinate the interplay of stably replicated genes with stably persisting environmental regularities, so that this web of interactions produces the reliable development of a functionally organized design. Selection is the only known counterweight to the tendency of physical systems to lose rather than grow functional organization. This means that the individually unique and unpredictable factors in the web of developmental interactions are a disordering threat to normal development. Selection built anti-entropic mechanisms into organisms to orchestrate transactions with environments so that they have some chance of being organization-building and reproduction-enhancing rather than disordering.

Evolutionary psychology was founded on a new theory of development that encompasses, reformulates, and (we believe) logically reconciles other views such as nativism, environmentalism, interactionism, developmental systems theory, and others. Readers who want to understand what evolutionary psychologists actually think about development need to consult the original sources (see, e.g., Tooby & Cosmides, 1990, 1992) rather than relying on critics' misconceptions. Below, we address several confusions.

Deficiencies in Basic Biology

Because developmental systems theorists are psychologists rather than a more interdisciplinarily inclusive team, it is not surprising that they also provide questionable characterizations of fields outside of psychology, such as genetics, developmental biology, and evolutionary biology (e.g., Lickliter & Honeycutt, 2003; Oyama, 1985, 2000; see also Gottlieb, 1997). Leaving aside the many out and out errors, Lickliter and Honeycutt (2003; like Oyama, 1985, 2000, and Gottlieb, 1997) present routine findings and viewpoints that have been generally accepted for decades as if they constituted a "conceptual revolution" that has "transformed contemporary developmental and evolutionary theory" (p. 819; e.g., that gene activity can be turned off and on by environmental or extracellular factors such as sensory experience, social context, or "hormones, temperature, diet, photoperiod" [p. 825]; that gene action is "dynamic, contingent, and bidirectional" [p. 821]). Indeed, in the history of biology, almost the first thing known about the regulation of gene expression was that it could be turned off and on by environmental factors, and that genes turn each other off and on. Jacob and Monod received the Nobel Prize 40 years ago for their discovery of the repressor–inducer dynamics of the lac operon and its regulation by environmental lactose—hardly an arcane or paradigm-shattering fact now (Muller-Hill, 1996).

It is equally a truism, rather than a breakthrough, to argue that

> the development of any individual organism is the consequence of a unique web of interactions among the genes it carries; the complex, multidetermined molecular interactions within and across individual cells; and the nature and sequence of the physical, biological, and social environments through which it passes during development. (Lickliter & Honeycutt, 2003, p. 820)

This is, to put it mildly, not a new insight for evolutionary psychologists but instead the traditional starting point for their research. The goal in evolutionary developmental psychology is to move beyond such bland general statements (true of all organisms at all times) by making detailed empirical tests of specific but theoretically illuminating hypotheses. For example, is differential experience navigating in natural environments responsible for the spatial cognition advantages exhibited by male rodents compared with female rodents (something that might well illuminate cognitive development of mammals in general)? Answer: No. Remarkably, cage-reared voles whose entire lifetime of spatial experience from birth to testing was a small cage, 4,000 times smaller than normal home ranges, exhibited navigational abilities that were just as good as their wild-caught parents. When the two sexes were raised in identical cage confinement, the male advantage was just as great as among their wild-caught parents—among the free-living ancestors, males had considerably more spatial experience than females because their home ranges encompassed several

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female home ranges (Gaulin, 1995). Gaulin's (1995) careful research in developmental evolutionary psychology decisively falsifies several prominent theories of mammalian brain development and even rules out the commonsense view that the development of sophisticated cognitive abilities in adult mammals necessarily requires extensive experience in the problem domain, as well as the commonsense view that the degree of adult ability necessarily corresponds to differential experience during development.

Furthermore, Lickliter and Honeycutt (2003) describe how certain species of coral reef fish are capable of sex reversal on the basis of social group composition and present this as one of the "cases of experience-dependent changes in body, brain, and behavior" that are supposedly providing "a radically different view from that assumed by evolutionary psychology" (p. 821). Far from being either unknown or in the least inconsistent with evolutionary psychology, one of us (H. Clark Barrett) spent a field season studying this phenomenon, and the case of sex-reversing fish has been for 2 decades a classic classroom example for evolutionary psychologists of an evolved, functional, developmentally dynamic relationship (e.g., Cosmides & Tooby, 1997, 2000, 2003). It is famously cited in the first evolutionary psychology textbook (Daly & Wilson, 1983), not just to make the same point that Lickliter and Honeycutt do about experience dependence and development, but to layer on the additional insight (missing from developmental systems theory) that developmentally orchestrated changes have been organized by natural selection to make such transformations typically fitness promoting for the organism.

The Role of Extragenetic Inheritance in Evolutionary Psychology

To pick one final example from Lickliter and Honeycutt's (2003) long series of purportedly neglected topics, they argue that new findings about "the role of extragenetic inheritance" (p. 824) contradicts evolutionary psychologists' supposedly "entrenched idea that stable, encapsulated genes are all an organism inherits from its ancestors in previous generations" (p. 825). Far from being new, such phenomena have been studied at least since Jollos (1921; for a wonderful review, see Jablonka & Lamb, 1995). But far from confounding evolutionary psychologists, these facts are thoroughly familiar to evolutionary psychologists because we as a community maintain a dual professional identity as evolutionary biologists. To take a typical example, Cosmides and Tooby have published extensive analyses of the evolutionary and behavioral significance of various of the extrachromosomal inheritance systems named by Lickliter and Honeycutt (basal bodies, organelles, membranes, cytoplasmic factors, etc.) over 2 decades ago (e.g., Cosmides & Tooby, 1981). Cosmides and Tooby are in no way exceptional—for example, the evolutionary biologist–evolutionary psychologist David Haig (2002) has been in the vanguard in exploring the naturally selected, sex-specific inheritance of gene regulation. Moreover, Tooby and Cosmides (2003) have been working on a general selectionist theory of the non-DNA based, cross-generational regulation of development, which would include non-sex-specific, *n*-generational cases of inheritance. These analyses apply to a large range of phenomena, including the uterine effects, methylation systems, and so on that Lickliter and Honeycutt claim evolutionary psychologists are unaware of.

Here as elsewhere, the fresh ingredient evolutionary psychologists contribute beyond developmental systems theory is not a different view of the existence or importance of an "interplay" (Lickliter and Honeycutt, 2003, p. 821) of multiple factors—genetic and nongenetic alike—in development. Instead, it is the recognition that natural selection acts to organize the relationship among all these determinants and interactants so that they usually produce functional outcomes. Evolutionary psychologists, and others, have long known that cross-generational extragenetic effects occur. This has led evolutionary psychologists into a theoretically motivated exploration of the potential functional organization in these effects (Cosmides & Tooby, 1981; Haig, 2002; Tooby & Cosmides, 2003).

In fact, Tooby and Cosmides's (2003) analysis of multigenerational systems addresses the cases that Lickliter and Honeycutt seem most interested in: To begin with, it must often be the case that there is a correlation of conditions among adjacent generations in certain respects (e.g., if a mother faces an exceptionally competitive, predatory, or food limited environment, then there is an increased probability that offspring will too—and with some decay function, that subsequent generations will as well). This would select for additional systems of inheritance that could transmit regulatory signals from immediately preceding generations (Tooby & Cosmides, 2003). The function of these signals is to help send individual development along pathways better suited to the conditions it is likely to face in its life. Given the operation of such systems, phenotypes would be partly inherited (i.e., cross-generationally regulated, with heightened parent–offspring similarity) in a way not attributable to DNA-sequence differences. These additional systems of inheritance would generally use other mechanisms, because DNA sequence transmission is usually too high fidelity to be useful for this purpose. For example, if the mother is made repeatedly fearful by exposure to predators in an enduringly predator-rich environment, then signals transmitted by methylation, in utero, or in early maternal care to the offspring could be designed to cause it to develop a predator-cautious phenotype usefully in advance of experiencing near capture by local predators—something that could be designed (depending on the temporal structure of the environment) to be passed on according to a decay function to subsequent generations. Similarly, if the parents (and/or other close ancestors) are food limited, and such a condition often persists across generations, then the offspring would benefit by developing a more frugal metabolism, selecting for an inheritance system that regulates metabolism across generations. To take a third case, if the parents are in an exceptionally competitive environment, then offspring would benefit by developing a more aggressive, territorial, competitive phenotype, with a greater tendency to emigrate, delayed maturation, and a greater tendency to bias uterine sex ratio toward the more dispersing sex. Not only have many of these empirical relationships been observed (Clark & Galef, 1995; Clark, Karpiuk, & Galef, 1993; Francis, Diorio, Liu, & Meaney, 1999; see discussion in Lickliter & Honeycutt, 2003), but they fit into an evolutionary psychological theory of functional development.

From this theoretical vantage point, cross-generational inheritance effects are not only unsurprising but are instead predicted for traits whose value depends on conditions that (a) frequently endure across more than one generation and (b) repeatedly cycle between states across several generations (Tooby & Cosmides, 2003). We predict that such inheritance systems should be generally limited to regulating traits that are either used starting early in the life cycle (e.g., frugal metabolism, predator-evasion tactics) or that are less costly or more effective if the organism begins to develop them prior to reliably detecting the conditions it will be facing (e.g., competitive ability, fat stores for famine).

Lickliter and Honeycutt (2003) write, and we agree, that it "seems to us that uncovering the network of factors (both internal and external to the organism) that bring about and maintain (or eliminate) transgenerational similarities or differences in behavioral traits should be a prominent goal of evolutionary psychology" (p. 829). In addition to the evolutionary psychology already cited in which this is a prominent goal, Boyd and Richerson (1985) have developed dual inheritance theory as a formal analysis of culture as an extragenetic inheritance system. Moreover, many evolutionarily oriented developmental psychologists, anthropologists, and behavior geneticists have done painstakingly detailed work teasing out the factors that lead to transgenerational similarities and differences in the development of behavioral traits (see, e.g., Belsky, 2000; Draper & Harpending, 1982; Rowe, 2000). Thus, instead of devoting "remarkabl[y] . . . little attention" (Lickliter & Honeycutt, 2003, p. 829) to such phenomena, in reality, evolutionary psychologists have considered and researched such topics in depth.

The Value of a Theory Depends on the Predictions It Makes

Evolutionary psychology is unusual and perhaps unique among theoretical orientations in psychology in the degree to which it derives principled predictions about previously unknown aspects of the species-typical psychological architectures of humans and other species. For example, using sexual selection theory, Gaulin (1995) was able to successfully predict (and thus to discover) the first mammalian species found that did not manifest a sex difference in spatial cognition. Daly and Wilson (1988) predicted and then discovered a remarkably extensive series of previously unknown relationships among life history, relatedness, violence, and motivation. Symons (1979) and Buss (1999) made and found support for an extraordinary number of predictions about human mating and other topics. Cosmides, Tooby, and colleagues have predicted and found a large number of patterns in human reasoning performance never before obtained experimentally, derived from the hypothesis that natural selection built specialized reasoning systems with procedures efficiently tailored to the recurrent properties of adaptive inferential problems involving cooperation (e.g., Cosmides & Tooby, 1992; Fiddick, Cosmides, & Tooby, 2000). To test the prediction of species-typicality, Sugiyama, Tooby, and Cosmides (2002) confirmed the operation of this system in other cultures. To test the neural reality of its predicted functional independence, Stone, Cosmides, Tooby, Kroll, and Knight (2002) confirmed the existence of selective deficits in this reasoning system due to focal brain damage.

Similarly, despite several decades' worth of studies seemingly establishing that people automatically and mandatorily encode the race of each individual they encounter regardless of context, Kurzban, Tooby, and Cosmides (2001) predicted that that encoding by race would instead be reversible—if experimenters manipulated evolutionarily predicted triggers. They hypothesized that race encoding was the by-product of cognitive machinery that evolved to detect coalitional alliances, and should only occur as long as race predicted probable coalitional affiliations. Experiments supported these predictions, showing that when cues of coalitional affiliation no longer track or correspond to race, subjects markedly reduce (or may even cease) encoding race, despite years of previous experience of race as a predictor of social alliance. Examples of principled prediction could be multiplied from the research of Gangestad, Kenrick, Nesse, Thornhill, and so on.

Developmental Systems Theory Makes No Predictions

In comparison, developmental systems theory makes no specific predictions of any sort and thus is useless as a scientific theory. Its uncontroversial assertion that everything potentially interacts with everything else—and that developmental outcomes are dependent on a convergent nexus of joint determination that varies depending on the case—is compatible, after the fact, with any imaginable research finding. It is, indeed, a statement of an absence of (and an aversion to) principled knowledge, disguised as a theory. Given a lengthy opportunity to mount a critique of any evolutionarily psychological research of their choosing, developmental systems theorists have nothing to say about how, in any particular case, a developmental systems theory approach would have predicted a different outcome from an evolutionary psychological approach. They have nothing to offer on how, even in principle, predictions could be derived from developmental systems theory. Lickliter and Honeycutt (2003), like Oyama (1985), object on principle to the idea that "the bodily forms, physiological processes, and behavioral dispositions of organisms can be specified in advance of the individual organism's development" (p. 820). Unless they are defending the trivial point that one cannot predict everything about an individual case with perfect certainty, they must be astounded that Henry Gray (1918) was able to predict (prespecify) in *Gray's Anatomy*, with extremely high accuracy, tens of thousands of precise anatomical details about the "bodily forms" of billions of humans who were born and developed in the century after he died. As Gray establishes, despite the fact that everything develops and may come to grief in an uncertain world, a great many things are nevertheless species-typical characteristics (including "bodily forms, physiological processes, and behavioral dispositions"). Self-defeatingly, developmental system theorists reject theories that presume to make predictions about reliable development, labeling them *predeterministic* and *preformationist* (Lickliter & Honeycutt, 2003; Oyama, 1985, 2000). In contrast, one goal of evolutionary psychologists has been to map the design features of our species-typical neurocomputational architecture at various points in development in terms of (a) the informational or circuit logic of the various components, (b) their neural structure, and (c) the developmental adaptations or underlying developmental programs that specify the conditional environmental input–phenotypic output relations that, given a specified sequence of environments, produce the developmental trajectory. Whenever the predictable (and functional) regularities that manifest themselves ubiquitously in species' development are discussed by others, developmental systems theorists mistake this for claims of an almost supernatural genetic predestination. That is, they seem confused by the profound difference between the true claim that normal members of a species embody predictable programs promoting reliable development, and the very distinct and false claims that following such developmental programs to a predetermined outcome is inevitable, unmodifiable, specified solely “in the genes” without regard to environment, or even that such developmental programs are necessarily hard to modify.

Evolutionary Psychologists Display an Intense Empirical and Theoretical Interest in Development

Lickliter and Honeycutt (2003) wrote that Tooby and Cosmides’s (1990) “explicitly preformationistic view virtually ignores the role of developmental processes in the realization of phenotypic characters or traits” (p. 821)—a “trivialization of developmental processes” (p. 822) that they attributed to evolutionary psychology as a field. We find such a contention bizarre, especially when the enormous lengths evolutionary psychologists make to test developmental hypotheses are compared with the practices of mainstream cognitive and social psychologists. Every evolutionary psychological hypothesis entails claims about (and so makes predictions about) development. Despite the sharp limitations on ethically possible developmental experiments on humans, evolutionary psychologists have found a number of ways of testing fine-grained developmental hypotheses about humans, from using other species as models (Gaulin, 1995) to using clinical populations with developmental disorders (Duchaine, 2002) to performing cross-cultural tests (Buss, 1989; Sugiyama et al., 2002) to relating life-events and circumstances to predicted developmental outcomes (Belsky, 2000; Daly & Wilson, 1988).

Indeed, it is hard to think of another research tradition in psychology that has paid as much theoretical attention to the issue of development and life history dynamics, wedded to so broad an array of empirical tests of its predictions. It is not an exaggeration to say that Daly and Wilson’s entire research program is built around extensive tests of the relationship between life history variables and their impact on motivation and social behavior across the life course (see, e.g., Daly & Wilson, 1988). Baron-Cohen’s (1995) explorations of theory of mind mechanisms through investigating autism and Duchaine’s (2002) tests of hypotheses about the development of face recognition are both elegant examples of how clinical disorders can illuminate the development of normal function. Lieberman, Tooby, and Cosmides (2003) have been able to test hypotheses about the developmental design of the human kin-recognition system and the developmental causes of moral opposition to incest by measuring the impact of many kinds of familial interaction and household composition from infancy through adolescence on incest aversion and familial bonding in the adults they study. More significantly, whereas the great majority of social psychologists are content with local undergraduates, Buss (1989) went to enormous effort to test for human mate-preference criteria in 37 different societies—that is, to test for the reliable development of ancestrally adaptive preferences despite broad cultural variation in modern developmental conditions.

In fact, cultural variation constitutes natural developmental manipulations; hence, cross-cultural tests are one of the key kinds of developmental experiments open to evolutionary psychologists. This is why evolutionary psychologists have placed so much emphasis on cross-cultural research (e.g., Barrett, Tooby, & Cosmides, 2003; Buss, 1999; Daly & Wilson, 1988) and why we ourselves have maintained a field station in the Ecuadorian Amazon for the past decade (e.g., Barrett et al., 2003; Sugiyama et al., 2002). Rather than uncritically assuming that major differences in direct experience and cultural indoctrination necessarily cause major differences in developmental outcome, we prefer to test such claims. For example, the ability to make inferences about predators and prey follows the same developmental trajectory among German and Shuar children. This is remarkable, considering that for Shuar but not German children, direct exposure to predation and the hunting and killing of animals is an everyday event experienced hundreds of times by the age of 5 (Barrett et al., 2003).

Organisms as Seen Through the Eyes of the Physicist

Among other innovations, the evolutionary psychological theory of development pays heightened attention to the specific causes that functionally coordinate the interaction among the genes, the developing organism, and the world. Indeed, the high degree of functional coordination seen in the gene–environment–organism interaction (which is responsible for the high degree of functional organization that reliably develops in the phenotype) requires a comprehensive explanation. The most distinctive feature of organisms is that they are full of exquisitely detailed functional organization on a scale as yet unparalleled in any human technology—something evident in thousands of cases, from the vertebrate eye, the wing of the albatross, and the web-building neural circuitry of the spider to the aerodynamic design of the feathery seed dispersal of wind-blown dandelion seeds.

Psychologists and biologists often exhibit only marginal awareness of how webs of extraordinary functional order interpenetrate and organize the phenomena they study, and so neglect to address the fundamental scientific problems their existence poses (e.g., Lickliter & Honeycutt, 2003; see also Gould, 1997a, 1997b; Oyama, 1985). We as human beings are easily seduced into taking the familiar for granted, as requiring little explanation. Consequently, it is very revealing—almost a revolutionary change in sensibility—to reexamine key issues in psychology and biology through the lens of physics, chemistry, and probability theory. In particular, the second law of thermodynamics (in both its classical and informational versions) is a fundamental law of biology and psychology as well as of physics because organisms and their brains are physical systems. From this perspective, it is living things that stand out as a remarkable departure from the physically normal (Schrödinger, 1944/1992), with the sterile surface of the moon, the comets, or solar flares being far more representative of matter in the universe than cicadas or flying fish. More specifically, what sets plants, animals, and other organisms apart from everything else in the universe is that manifest in their designs are dazzlingly improbable arrays of highly tuned interrelationships—a high order that is functional (Dawkins, 1986; Tooby & Cosmides, 1992).

To take just one example, the lens of the eye is transparent, despite the fact that vanishingly few protein polymer mixtures are transparent; the lens focuses light into an image, despite the fact that vanishingly few out of all possible geometric shapes do this; the retina is parallel to the lens and lies in the focal plane, despite the fact that very few relative orientations would lead to this outcome; the cells in the retina contain organelles with photosensitive pigments (despite their chemical rarity); these pigments are sensitive to those wavelengths that the lens focuses rather than other portions of the spectrum; and on and on through thousands of sensitively interrelated design features (see, e.g., Palmer, 1999; Rodieck, 1998).

There is nothing in the processes of chemistry or physics that predisposes molecular arrangements to occur in these truly rare functional relations as opposed to the massively more common (and hence more likely to be physically generated) nonfunctional ones. Indeed, ordinary transactions between such ordered systems and the environment tend to disorder such relationships, sooner or later producing the state of disorder called death. In contrast, nonliving collections of atoms tend not to be highly organized, and it makes no sense to identify aspects of craters, cometary plumes, solar storms, or other nonliving aggregations as functional for the phenomena that exhibit them. They have no adaptations.

Thermodynamics informs us that, in general, such functional order does not come about spontaneously: Geology does not produce frescoed Tuscan villas, hurricanes do not assemble violins, and shaking up mixtures of sugar, milk, and dirt will not produce komodo dragons or congressmen. More generally, because functional orderings of atoms are a vastly smaller subset of arrangements than nonfunctional ones, they are astronomically more improbable. Because the second law of thermodynamics states that physical systems tend to move toward more probable states, they tend to move away from organization on their path toward maximum disorder (Feynman, Leighton, & Sands, 1963). Even more depressing, as highly ordered physical systems, organisms should tend to slide rapidly back toward a state of maximum disorder or maximum probability (with death occurring at some intermediate point in the decline, shortly before rot). “It is by avoiding the rapid decay into the inert state,” Schrödinger (1944/1992) said, “that an organism appears so enigmatic” (pp. 69–70).

Thus, to study organisms scientifically is to be confronted with the following questions: Why is it that living things exhibit a miraculously high level of order not found among the nonliving? Where does this high level of order come from? Why is it functional order? and In the history of life, what causes increasing order to accumulate so often across geological time? Over the individual life span, what causes organisms to start out as single cells and then anti-entropically climb to dizzyingly greater heights of order (in the case of humans, to cell populations in the trillions built into intricate intercellular structures such as the eye, vasculature, and brain)? As if that were not enough, how is it that living collections of atoms are drawn from that even more immensely minute subset of ordered arrangements that reliably construct new systems that duplicate the functional order in the parent physical systems—that is, why do living systems reproduce or replicate (Paley, 1828)?

Darwin (1859) was the first person to work out the key to answering these questions in a way that could potentially satisfy a modern physicist (see also Dawkins, 1986). Darwin’s answer to the thermodynamical puzzle of organisms was to identify the causal links between self-reproduction and the high functional organization of organisms. Given the existence of an initial physical system ordered in such a way that it causes itself to reproduce, reproduction spreads its near-duplicates in the world, replacing or more than replacing those that die. Those near-duplicates whose order is degraded reproduce their designs less successfully, and so eventually disappear. The rare near-duplicate whose randomly generated variant design happens to be “better”—that is, that causes it to interact with the stable structure of the environment in a way that systematically increases its rate of reproduction—therefore increases its frequency in the world. It is only among the world of replicators that chance improvements in design mechanically single themselves out for disproportionate self-multiplication, spreading to become the new design baseline. Entirely without agency, the interaction between the properties of reproducers, errors in copying, and the enduring properties of the world naturally cause order to accumulate along (some) lineages of physically reproducing systems—something that would otherwise be a thermodynamic miracle. This is why plants and animals (as reproducers), but not clouds or meteorites (as nonreproducers), show an incredible functional organization.

Lessons for Psychology From Thermodynamics and Darwinism

The most basic lesson is that natural selection is the only known natural process that pushes populations of organisms thermodynamically uphill into higher degrees of functional order, or even offsets the inevitable increase in disorder that would otherwise take place. Therefore, all functional organization in undomesticated organisms that is greater than could be expected by chance (which is nearly all functional organization) is ultimately the result of the operation of natural selection and hence must be explained in terms of it (if it is to be explained at all). This is why understanding natural selection is enormously beneficial to any theoretically principled psychology. In effect, natural selection defines the design criteria to which organisms were built to conform. This is why knowledge of ancestral natural selection combined with knowledge of ancestral environments provides a principled theoretical framework for deriving predictions about the reliably developing design of the human mind. Natural selection is (a) the set of enduring, nonrandom, cause-and-effect relationships in the world that (b) interact with the reliably developing features of organisms (c) in such a way that they consistently cause some design variants to reproduce their designs more frequently than others because of their design differences. Hence, those traits that do not reliably develop across generations cannot be systematically interacted with by selection and thus will not be organized by the long-term operation of selection. Reciprocally, if a property of the world does not stably endure across generations, then it will not last long enough to cause some design features to supplant others in large populations, and its effects will not show up in the species-typical designs of organisms. Selection brings about a functional coordination between the stable, long-term properties of environments and the stable, cross-generationally recurrent, reliably developing (and hence predictable or prespecifiable) properties of organisms. In contrast, there is no process that guarantees that unique, novel interactions between environments and organisms will be functional. Hence, natural selection predicts and explains the extraordinarily nonrandom, functionally organized relationships that interpenetrate the species-wide designs of all organisms, including humans. Whenever one sees functional order, one is seeing the downstream contrivances of natural selection.

The Developmentally Relevant Environment as a Second System of Inheritance

One thing to notice in this view of Darwinism is that the high level of functional order in organisms is caused by, and dependent on, those features of the world that both endure across generations and that interact with the organism's design (we call this the *developmentally relevant environment*). From the point of view of any given subcomponent of the organism, other parts of the organism are, of course, stable features of the environment, and so high levels of functional interrelationship accumulate among a body's parts. In addition, some aspects of the environment outside of the organism are also enduring features of the ancestral world that interacted reliably with the organism's design, and so subcomponents of the organism typically manifest highly functional interrelationships with them. The developmentally relevant environment constitutes a second system of inheritance analogous to the genes. This second system of inheritance always fully participates with the genes in the joint determination of development.

Thus, a close examination of how natural selection actually drives evolutionary processes leads to a very different view of how genes and the environment are related:

> Evolution acts *through* genes, but it acts on the *relationship* between the genes and the environment. Hence, the "environment" is just as much a part of the process of evolutionary inheritance as are the "genes," and equally as "biological" and evolved. (Tooby & Cosmides, 1990, pp. 19–20)

Reliably developing species-typical design is caused just as much by the evolutionarily stable features of the world as by the genes; they jointly determine the phenotype.

These considerations lead to a very different theory of development than nativism, environmentalism, developmental systems theory, and other existing alternatives. The developmentally relevant environment can usefully be viewed as a second system of inheritance comparable in some ways with genetic systems of inheritance (Tooby & Cosmides, 1990, 1992). A zygote in an environment can be seen as inheriting a set of genetic determinants (including cellular machinery) and simultaneously also a set of environmental determinants. The environmental determinants are transmitted or inherited in a peculiar fashion—they simply endure as physical arrangements in the world across generations over the range where the lineal series of zygotes appear. Some environmental determinants, indeed, are perfectly replicated across generations (e.g., the three-dimensional nature of space, the properties of light, the properties of chemical compounds). Moreover, natural selection sorts between design variants depending on which interacting gene–environment inheritances produce organisms that successfully develop functional designs. That is, organismic designs successfully reproduce based on the degree to which their genetic and environmental inheritances are coordinated with each other. The longer selection has had to coordinate these two inheritances, the more evolved functional design is able to be realized in development. Change in either inheritance (either though genetic mutation or environmental change) disrupts the coordination, and the greater or more rapid the change, the greater the disruption. Moreover,

> no organism reacts to every aspect of the environment: Instead, the developmental programs rely on and interact with only certain defined subsets of properties of the environment, while others are ignored. . . . Over evolutionary time, genetic variation in developmental programs (with selective retention of advantageous variants) explores the properties of the environment, discovering those that are useful sources of information in the task of regulating development and behavior, and rendering those features of the environment that are unreliable or disruptive irrelevant to development. Across generations, this process of exploration of alternative gene-environment relations operates by varying developmental programs with respect to (a) what kinds of inputs from the environment they accept or are sensitive to, and (b) how they shape phenotypic outcomes in response to these inputs. The "environment" of an animal—in the sense of which features of the world it depends on or uses as inputs—is just as much the creation of the evolutionary process as the genes are. Thus, the evolutionary process can be said to store information necessary for development in both the environment and the genes. (Tooby & Cosmides, 1990, pp. 19–20; see Tooby & Cosmides, 2001, for how aesthetic motivations may function to guide developmentally advantageous transactions with the world)

Despite developmental systems theorists' misreading of the word *program* to mean a linear track, computational language allows the principled description of functional interaction that is complexly "dynamic, contingent, and bidirectional" (Lickliter & Honeycutt, 2003, p. 821).

Obviously, this theory of development is not gene centered or a form of *genetic determinism*, if by that one means the idea that genes by themselves determine everything, immune from environmental influence, or even that genes determine "more" than the environment does. All aspects of the phenotype are equally codetermined by this interaction (see Tooby & Cosmides, 1990, pp. 19–20). But although not gene centered, this view is very much natural selection centered, because it is natural selection that chooses some genes rather than others and in so doing orchestrates the interaction between the two inheritances so that high degrees of recurrent functional order can emerge and persist, such as eyes or maternal love.

Moreover, this view explains how reliable development both can and does ordinarily occur—that is, we see in almost all individuals the emergence of a robust, "prespecified" species-typical design (e.g., what can be seen in *Gray's Anatomy*) with respect to almost all species-typical adaptations in almost all individuals. The species-typical features of the genome interact with the features of the evolutionarily long-enduring, species-typical environments to produce the species-typical design observable in all of us. Failures of reliable development are attributable to genetic mutation, to environmental mutation (change), or both.

Developmental systems theorists Lickliter and Honeycutt (2003) argue that individual development "is the consequence of a unique web of interactions" (p. 820) and strongly contest the idea that the "phenotypic traits or characters can be prespecified in advance of individual ontogeny" (p. 828). If we truly were the product of a unique web of interactions, and nothing could be prespecified, then the second law of thermodynamics tells us that every individual would start out and end up a horrifying monstrosity.

The answer to this conundrum is that evolution is the story of ceaseless repetition and endless reincarnation. In this generation, all of our parts fit together reasonably well (both with each other and with the demands of the world) because tandem inheritance combinations have been generated for innumerable generations—

that is, existing gene–organism–environment webs were mostly tried out in past generations. Poorly coordinated ones were discarded (including a very high proportion of the novel, unique combinations), and the nonunique functional interactions were retained, to be generated with high probability in this generation. The fact that we have all been here before is a very good thing, because it is only this regularity of interaction, from generation to generation, that allows organisms to climb toward a tolerable level of functional organization and inclines them away from depending on the aspects of the environment that are unpredictably variable and hence disordering. As evolutionary psychologists, we believe in design reincarnation based on two inheritances, not genetic preformationism based on one.

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Call for Nominations

The Publications and Communications (P&C) Board has opened nominations for the editorships of ***Comparative Psychology***, ***Experimental and Clinical Psychopharmacology***, ***Journal of Abnormal Psychology***, ***Journal of Counseling Psychology***, and ***JEP: Human Perception and Performance*** for the years 2006–2011. Meredith J. West, PhD, Warren K. Bickel, PhD, Timothy B. Baker, PhD, Jo-Ida C. Hansen, PhD, and David A. Rosenbaum, PhD, respectively, are the incumbent editors.

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