Research in Human Development

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/hrhd20

How New Ideas in Physics and Biology Influence Developmental Science

Gary Greenberg [a]

[a] Wichita State University

Published online: 05 Feb 2014.

To cite this article: Gary Greenberg (2014) How New Ideas in Physics and Biology Influence Developmental Science, Research in Human Development, 11:1, 5-21

To link to this article: http://dx.doi.org/10.1080/15427609.2014.874730

Research in Human Development, 11: 5–21, 2014

ISSN: 1542-7609 print / 1542-7617 online
DOI: 10.1080/15427609.2014.874730

Routledge
Taylor & Francis Group

ARTICLES

How New Ideas in Physics and Biology Influence Developmental Science

Gary Greenberg
Wichita State University

This article reviews how ideas from 20th century physics and biology have come to play important roles in the study of development and how these ideas have informed a relatively new paradigm in developmental science: relational developmental systems, a synthesis of developmental biology and developmental psychology. Employing concepts such as emergence and self-organization, epigenetics and epigenesis, and an ontological framework that stresses levels of increasing organization and complexity, the relational developmental systems paradigm embraces a thoroughly holistic and nonreductionistic account of development and behavioral origins. It furthermore promotes psychology as a unique science, irreducible to biological science—though genes, brains, and other biological processes are factors that participate in the developmental process, such factors do not cause behavioral origins and are only explicable in the context of the developing system as a whole.

Among the recent intellectual changes in developmental psychology has been the introduction of a theoretical perspective identified as relational developmental systems (RDS) (Overton, 2013). This is an approach that fundamentally rejects the idea that psychology is a biological science and that genes and brains have primacy in ontogeny, behavioral as well as biological—rather, genes and brains are merely other participants in developmental processes. Being a relatively new approach to behavior it relies on newer concepts from the other sciences: from physics, self-organization and emergence and from biology, epigenetics and epigenesis. It is, as well, a holistic, nonreductionistic approach to organisms and their development.

As the above suggests, the appearance of theoretical sophistication in developmental psychology is relatively new. "Currently, the focus on theoretical explanation and on finding the nature of the basic developmental mechanisms comes mainly from system-oriented researchers" (van Geert, 2009, p. 243), grounded in evolutionary theory and developmental psychobiology. This

Address correspondence to Gary Greenberg, 3260 N. Lake Shore Dr. (8B), Chicago, IL 60657. E-mail: gary.greenberg@wichita.edu

article focuses on a unique and promising approach to developmental psychology—relational developmental systems, an iteration of nonlinear dynamical systems. “There is a continued tendency among nonlinear dynamical systems (NDS) scholars to reflect on their work in terms of a major paradigm shift in psychology” (Koopmans, 2009, p. 507). Extended discussions of this paradigmatic change in developmental science can be found in Overton (2011, 2012), Overton and Lerner (2012), and Lerner and Benson’s (2013) historical summary.

I arrived at this perspective gradually through a series of introductions to the related work of several psychologists, Z.-Y. Kuo, T. C. Schneirla, J. R. Kantor, Gilbert Gottlieb, and Richard M. Lerner. My undergraduate course work at Brooklyn College exposed me to the integrative levels ideas of T. C. Schneirla (Aronson, Tobach, Rosenblatt, & Lehrman, 1972) via two classes from one of his graduate students, Howard Moltz. My graduate work at the University of Wichita explored the interbehaviorist perspective of J. R. Kantor (Kantor, 1959; Pronko, 1980) whose theoretical writings are in many respects similar to those of Schneirla (Lazar, 1978). Professors there encouraged me to read widely, and I eventually discovered the works of Gilbert Gottlieb (e.g., 1992), a developmental psychobiologist. A fortuitous postdoctoral association with Ethel Tobach, another of Schneirla’s graduate students, at New York’s American Museum of Natural History, culminated in a lecture series devoted to the exploration of Schneirla’s ideas (Greenberg, Partridge, Weiss, & Pisula, 2004; Greenberg & Tobach, 1984). It was through that conference series that I came in contact with and developed a continuing relationship with Richard M. Lerner (1995) and, as a result, with many of the ideas associated with RDS.

My journey to this approach to psychology mirrors, in some respects, that of Lerner’s (2002). Similar to his journey, my definition of how I defined my science was altered (developed) as I learned more. Originally a comparative psychologist, I now consider myself a developmental psychobiologist (Michel, 2013), having come to consider psychology a developmental science (Greenberg, Partridge, Mosack, & Lambdin, 2006) and a natural science of behavior.

PSYCHOLOGY IS A UNIQUE NATURAL SCIENCE

Many scientists and nonscientists alike continue to embrace the worn-out schism between the natural and behavioral, or social, sciences (Christakis, 2013). In doing so, psychology is seen to be a weak sister among the community of sciences. Beins (2012) went so far to suggest that this schism renders psychology “not quite a science; rather we are a something-other-than-science-science” (p. 1). As a result of my Kantorian interbehavioral graduate training (Greenberg, 2008), I have long argued that because there is only science and nonscience, psychology (and the other behavioral sciences) is simply another one of the natural sciences (e.g., Greenberg, 2011; Greenberg & Partridge, 2010). Of course, this is not new with me as a strong case can, and has been, made that “Psychology or the science of the mind was conceived as a natural science in the seventeenth, eighteenth, and nineteenth centuries” (Hatfield, 1995, p. 216). Although we usually trace the origins of scientific psychology to Wilhelm Wundt in Germany and William James in the United States around 1879 (Boring, 1950), at the same time psychology was being identified as a biological science by British medical physiologists such as William Carpenter and Henry Maudsley, themselves influenced by Darwin, Romanes, and C. Lloyd Morgan (Hatfield, 2003).

Today there can no longer be any doubt that psychology was not only linked to the other sciences, but also continues to have an important impact on them (Boyack, Klavans, & Borner, 2005). In fact, with respect to neuroscience, "psychology has led the way in the study of the brain" (Hatfield, 2000, p. S396). Conceptualized in this way, behavior is as natural a phenomenon as rolling balls down inclined planes was for Galileo. However, though initially allied with biology, and seen to be a biological science (e.g., Hatfield, 2003), psychology today is best understood to be a unique science (Greenberg, 2011), biology simply providing a set of participating, and not causal, factors in the genesis and development of behavior. There is much to agree with in Pronko's (1988) comment that "We must not neglect genetic and other biologic factors, but, instead of treating them as causal, we regard them as *aspects* of an integrated field event or events" (p. 78).

In the middle of the 20th century, Brunswick (1956), reiterating the argument that psychology was a natural science, hinted at some of the ideas I am going to develop in this article—that psychology is indeed a natural science; that psychology, long suffering from physics envy, "was to be placed fully under the auspices of the methodologically most rigorous of its older sister disciplines, physics" (p. 151); that molar, or holistic, ideas had an important role to play in understanding behavior; and, presciently, anticipating the contemporary relationship of psychology with dynamic systems theory, discussed here as "RDS."

In 2014, it is appropriate and fitting to see psychology not as Brunswick did in 1956 as a relatively youthful science, but rather, as a science mature enough to stand on its own and not as a subset of biology, the discipline from which it emerged. As early as the 1920s, J. R. Kantor (1924, 1926) was making this case and arguing that, though biology is important for psychological events, psychology was a unique psychological science. T. C. Schneirla (1949) later joined in discussing psychology in this way. Contemporary developmental systems psychologists have embraced this understanding of psychology (e.g., Ford & Lerner, 1992).

Scientists from other disciplines have recognized this as well. As the physicist P. W. Anderson (1972) put it: "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" (p. 393). As pointed out by an ecologist, 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 which do not belong to sciences lower in the hierarchy (Bauchau, 2006). The physicist Paul Davies (2003b) has said this another way: "At each level of description, from atoms up through molecules, cells, organisms, and society and culture, genuinely new phenomena and properties emerge that require laws and principles appropriate to those levels" (p. 5). In a nonlinear universe, "small changes on one level of organization . . . produce large effects at the same or different levels" (Coveny & Highfield, 1995, p. 9). This theme of growth and maturity is of course not unique to psychology. For example, a similar situation existed with regard to biology in the early 1900s when Woodger (1929) argued that it 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).

Today, psychology is its own science, separate and distinct from biology, with its own unique principles searching for its own unique laws. We use the terms *law* and *theory* rather loosely in psychology, but, as we are still searching for all the pertinent variables that influence behavior, we have no statements with the power, for example, of natural selection, of gravity, or of relativity (among the best discussions of just what theories are and are not is that by Uttal, 2005).

Psychology is even short on laws, with the possible exception of Thorndike's law of effect (i.e., reinforcement). Even biology, a much older science, similarly lacks laws. McShea and Brandon (2010) identify the idea of "increasing complexity through evolution" as biology's first law.

A HOLISTIC PSYCHOLOGY AND DEVELOPMENTAL SCIENCE

As Koopmans (2009) suggested, "There continues to be a need in the field for alternatives to a reductionistic version of psychology" (p. 523). Although some would argue that behaviorism is, or was, that alternative, its influence waned in the latter part of the 20th century. Instead, in endorsing the holistic position of relational developmental systems, I agree with the need for a contemporary alternative to reductionistic thinking and believe this is that viable alternative. Many of the ideas explored in the articles in this special issue of RHD are linked by three important concepts: That of integrative levels, of increasing complexity with evolution (biological as well as cosmological), and of contextualism.

A crucial idea is the view that the universe is ordered as a family of hierarchies in which natural phenomena exist in levels of increasing organization and complexity. This has been summarized by Aronson (1984) in the following way: The levels concept

> is a view of the universe as a family of hierarchies in which natural phenomena exist in levels of increasing organization and complexity. Associated with this concept is the important corollary that these successions of levels are the products of evolution. (p. 66)

The idea of hierarchy, even among the sciences, is not new. The sciences can be divided into areas of study based on quantitative 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. This idea was seemingly originated by Auguste Comte in the late 1800s (see Boorstein, 1998, p. 223) and was later developed by others such as the biologist Novikoff (1945), the philosopher Feibleman (1954), and the psychologist Schneirla (1949). This idea is now widely accepted as a fundamental principle of science. With respect to biology, and especially to evolution, Saunders and Ho (1976, 1981, 1984) suggest that this may be considered a second principle of Darwinian evolution, after natural selection. Other scientists have also flirted with the idea that increasing complexity may be a universal principle (e.g., Davies 2003a). As Chaisson (2001) commented, "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).

With respect to developmental science in particular, it is of interest that some of the ideas central to my discussion were introduced early on by Heinz Werner (Valsiner, 2005b; Werner, 1948). Two crucial ideas in his approach to development were those of hierarchy and emergence. He understood, with others who came before and after, that hierarchical organization was a general principle of nature and of science (Valsiner, 2005a): hierarchy of biological forms, of mental functions, of neural functioning, indeed—of the world (Werner, 1948). Werner believed that during development functions of the organism "emerged" as studyable elements (Glick, 1992), in much the same way I discuss language in great apes elsewhere in this article. In concert with contemporary developmental science, Werner was, as well, a holist, perhaps a result of his familiarity with the Gestaltists of his day (van der Veer, 2005). I refer to Werner here not only to underscore his significance for contemporary developmental science but to illustrate the development of developmental science itself.

New ideas and concepts in the sciences are characteristic of this contemporary holistic approach. Stuart Kauffman (2008), a leading proponent of this new paradigm in science, described matters as follows: "We are coming to a scientific worldview that takes us into subjects normally thought to lie outside the realm of science" (p. 120) and "Without vitiating any law of physics, physical laws alone do not describe the causal unfolding of the universe" (p. 131) and "It is an amusing fact that scientists who eschew philosophy invariably espouse a philosophy of science that is long outdated" (p. 147).

THE PROPERTIES OF DEVELOPMENTAL SCIENCE AND PSYCHOLOGY

As I discuss in this section, psychology is among the most complex of the sciences. Its complexity stems from the fact that behavior is a result of a myriad of factors, among them phylogeny, ontogeny, experience, culture, and genetics (see Greenberg, Callina, & Mueller, 2013 for a discussion of these factors). A further source of the complexity of behavioral development is the organisms' own experience with itself during its development, that is, "self-stimulated experience" (Michel, 2007). Another way of saying this is that individuals are themselves sources of their own development (Lerner & Busch-Rossnagel, 1981). Being a developmentalist, Gilbert Gottlieb believed that experiences formed the basis of all behaviors, though those experiences were often nonobvious.

> As for nonobvious experiences, who could have dreamed that squirrel monkeys' innate fear of snakes derives from their earlier experience with live insects (Masataka, 1994)? Or that chicks perceiving meal worms as edible morsels is dependent on their having seen their toes move (Wallman, 1979)? (Gottlieb, 2001, p. 2)

In addition, as my title suggests, concepts from other sciences further complicates our full understanding of behavioral origins and development. Thus, this section of my article deals with the following problem:

> perhaps the most baffling property of biological complexity—the well-known ability of living systems to quite literally take on a life of their own and behave as autonomous agents rather than as slaves to the laws of physics and chemistry. . . . How does this come about? How does a physical system harness physics and chemistry to pursue an agenda? Somewhere on the spectrum from a large molecule through bacteria and multicelled organisms to human beings something like purposeful behavior and freedom of choice enters the picture. Complexity reaches a threshold at which the system is liberated from the strictures of physics and chemistry while still remaining subject to their law. (Davies, 2003b, p. 8)

The early dynamic multilevel transactions integrating biology and ecology in the course of development (e.g., Gottlieb, 1973, 1984, 1985) were prescient of major advances in the field resulting from empirical findings in molecular genetics and cell development, along with conceptual and methodological tools from nonlinear dynamic systems and complex adaptive systems theory. As such, in this article I am attempting to demonstrate these linkages and contemporary ideas issuing forth from nonlinear dynamic systems theory and complex adaptive systems theory. Although this nonlinear perspective is still not universally accepted, it is refreshing to note that some in developmental science and psychology have been responsive to these newly introduced concepts of nonlinear dynamics, self-organization, emergence, and other ideas I discuss in this section. Overton, for example, acknowledged their significance for developmental science as early as 1994. In Koopman's (2009) assessment, nonlinear dynamics

> produces a shift in research priorities. Part of the excitement that radiates from the work of nonlinear dynamics has to do with its exploratory nature and with the sense of breaking new ground in psychology and offering new modeling techniques and analytical strategies. (p. 509)

The state of this perspective in developmental science has been captured by Witherington (2007):

> A decade ago, developmental psychology could easily be characterized as a field in search of ontological unity. . . . Since then the field has witnessed what Lerner (2006) has described as "the ascendency of a developmental systems frame" (p. 5)—a widespread commitment to thoroughly relational, integrative conceptions of development that promise to transcend false dichotomies and unify the field. Prominent among the metatheoretical frameworks rooted in this developmental systems frame is the developmental systems perspective (DSP), which attempts to explain, through the systems' concepts of self-organization and holism, how developmental patterns arise. (pp. 127–128)

Although many relational developmental systems writers seemingly restrict their application of these principles to human life-span development, I see merit in utilizing this approach to understand behavioral development across the animal spectrum (Greenberg & Haraway, 2002). This approach appears to me to represent a "general psychology," if you will. In describing the contemporary contributions of other sciences to our own, my focus here is on concepts of self-organization and emergence from physics, on the cosmological and biological evolution of increased complexity since the Big Bang, on the important organizing principle of integrative levels, on neuroscience, molecular biology, genomics, and on epigenetic evolution.

I have long held that psychology is a more complex science than those which stand lower than it in the hierarchy of the sciences. This is nowhere made so clear as in the recent discussion of "social genomics" by Slavich and Cole (2013). Despite important recent critiques of behavior genetics (e.g., Charney, 2012; Wahlsten, 2012) and neuroreductionism (Uttal, 2011), there remain crucial genetic and neurological influences on behavior. Such influences are part of the participating biological factors which affect behavior. As Bertalanffy (1956) reminded us more than 50 years ago, "Rejecting biologism does not mean we can neglect biology" (p. 34). Slavich and Cole so crucially pointed out that genes are turned on and off throughout our lifetimes, "The human genome, therefore, is not a blueprint for human potential" (p. 331).

What makes this extremely complex is our current understanding that all aspects of our lives, social situations especially and even our thought processes, have profound influences on which and when genes are activated and expressed and suppressed. Of course, most social situations are not one-time events; a spousal breakup, for example, may have prolonged and profound effects on hormone levels, themselves being only some of the chemical influences on nervous system activation and genetic expression. There is, as well, the potential for such social stressors on genetic expression to have an impact on disease susceptibility. Further complicating these issues for human psychology: "Social influences regulate gene expression on an individual level, but they may also be involved in gene expression at a collective group level" (Slavich & Cole, 2013, p. 340).

It is long past time for us to progress in our science beyond that of traditional reductionism (Kauffman, 2008; Lerner & Benson, 2013; Mahner & Bunge, 1977; Nagel, 2012), and to acknowledge and embrace the idea of holism. It is not that we should reject reductionism in toto; it has, of course, been a powerful, fruitful tool from the beginnings of science. Reductionism, albeit "moderate reductionism" (Mahner & Bunge, 1997), still has a place in our science despite our having entered the era of holism. This weak form of reductionism reflects "the strategy of reducing whatever can be reduced (fully or partially) without ignoring variety and emergence" (p. 116), even "radical reductionism," adds Bunge (1977), "is sometimes heuristically fertile, since it stimulates the search for profound explanations, *in particular explanations in terms of adjacent levels*" (p. R80, emphasis added). In this context and with respect to relational developmental systems theory, Lerner and Benson (2013) underscored that all levels and contexts are involved (fused) in influencing development across the life span (see also Hood, Tucker-Halpern, Greenberg, & Lerner, 2010).

The concepts of hierarchy, integrative levels and systems, self-organization, complexity, epigenetics, epigenesis, and emergence so central to the new orientation brought to psychology, have been rather fully developed over the last quarter century and are being employed with considerable alacrity by scientists in many disciplines. Indeed, with respect to the relational development systems model, a significant body of empirical work has been accumulated over the past 25+ years based explicitly on these dynamic systems models. Nor have methodological issues been neglected. As a result of the convergence of the ideas I have discussed, developmental psychologists now have at their disposal a conceptual architecture and an emerging methodology that is commensurate with their core theoretical principles (e.g., Molenaar, 2010). Not only do empirical data indirectly support inferences about the role of integrated biopsychosocial systems in shaping phenotypic outcomes, but also theoretical physicists and mathematicians have demonstrated that these same principles hold widely. Thus, there is now a set of methodological tools using systems methods that have the capability of testing many of the developmental systems postulates directly (Urban, Osgood, & Mabry, 2011). However, though methodologies are routinely used in other systems and disciplines, they have only slowly begun to be used in developmental science (Mabry & Urban, 2011; Urban et al., 2011).

Just as the traditional materialist, reductionist approach in physics and the other sciences has failed to live up to its initial promise (Kauffman, 2008) and has since given way to a more holistic, field-oriented, and contextual paradigm (Davies & Gribbin, 1992; Goodwin, 1994), so too psychology and developmental science have begun to give up their adherence to an old-fashioned physics in favor of this newly emerging scientific paradigm (e.g., Chorover, 1990; Lerner, 1998). This new perspective, and its extremely broad application, can be summarized as follows:

> since the 1960s, an increasing amount of experimental data . . . imposes a new attitude concerning the description of nature. Such ordinary systems as a layer of fluid or a mixture of chemical products can generate, under appropriate conditions, a multitude of *self-organisation phenomena* on a macroscopic scale—a scale order of magnitude larger than the range of fundamental interactions—in the form of spatial patterns or temporal rhythms. . . [Such states of matter] provide the natural archetypes for understanding a large body of phenomena in branches which traditionally were outside the realm of physics, such as turbulence, the circulation of the atmosphere and the oceans, plate tectonics, glaciations, and other forces that shape our natural environment; or, even, the emergence of self-replicating systems capable of storing and generating information, embryonic development, the electrical activity

> of the brain, or the behavior of populations in an ecosystem or in economic development. (Nicolis, 1989, p. 316).

I believe that such ideas apply equally in psychology and developmental science.

Emergence and Self-Organization

It is surprising where one sometimes gains advice. In this instance I note that *Alice in Wonderland's* Red Queen believed it to be always helpful to "begin at the beginning." For this discussion the beginning is the Big Bang (Singh, 2004), the ultimate source of everything. The first elements produced, hydrogen and helium, eventually gave rise to all else. Another way of saying this is that as a corollary of the Big Bang, given enough time hydrogen and helium become sentient beings. "Matter has an innate tendency to self-organize and generate complexity. This tendency has been at work since the birth of the universe" (Coveny & Highfield, 1995, p. 10). What we see now in the universe is the result of the processes of emergence and self-organization, and for this discussion, these ideas from physics are central to the developmental systems metatheory (Witherington, 2011). Reid (2007) provided an apt definition of these processes:

> Emergence is the spontaneous appearance of novel qualities through the interactions and constraints of generative conditions, consisting of the dynamic structure of the original, and properties of its environment. Thus stated, emergence includes a wide range of physical events from the Big Bang to the physicochemical reactions that produce liquid water from hydrogen and oxygen at appropriate temperatures and pressures. (p. 290)

An early discussion of this process by Oparin (1961) is surprisingly contemporary in its understanding of these processes and reflects the themes of this chapter:

> The facts at our disposal indicate that the origin of life was a gradual process in which organic substances became more and more complicated and formed complete systems which were in a state of complete interaction with the medium surrounding them. . . . Following the path of the emergence of life in this way . . . there arose new biological laws which had not existed before. (pp. 36–37)

"One of the most beautiful and profound ideas I know, and one whose power is not widely enough appreciated, is the idea of emergence and emergent properties" (Christian, 2013, p. 174). That it is not widely appreciated is surprising given that this concept was applied to psychology by the founders of modern experimental psychology, William James and Wilhelm Wundt (Sawyer, 2002), and even earlier by John Stuart Mill, the father of British emergentism (McLaughlin, 2008). Suffice it to say, the development of behavior is not the result of instincts (Bateson & Curley, 2013), despite the popularity of that idea among evolutionary psychologists (Blumberg, 2005); nor does the old instinct/learning dichotomy provide the answer, that is, "if it is not instinct it must be learning." There is much more than these two sources responsible for behavioral origins—that much more is "development"! Here is how Daniel Lehrman characterized this as early as 1953:

> The problem of development is the development of new structures and activity patterns from the resolution of the interaction of *existing* structures and patterns, within the organism and its internal environment, and between the organism and its outer environment. At any stage of development, the new features emerge from the interactions within the *current* stage and between the *current* stage and the environment. (p. 345)

With respect to learning, we now know that in addition to the two traditionally recognized forms of learning, Pavlov's classical conditioning and Skinner's operant conditioning, a third form is now recognized, that of emergent learning (Rumbaugh, Washburn, & Hillix, 1996). With this theoretical formulation, Rumbaugh has linked the study of cognition to the most contemporary formulations of the newly developing sciences of complexity and dynamic systems, providing more mathematical and empirical alternatives to traditional thinking about cognitive behavior. The point is that "emergent learning' proposed by Rumbaugh et al. (1996) described the long range outcomes of a learning system that cannot be reduced to its respondent and operant elements; emergent learning thus constitutes a separate class of learning origins. The work of Thelen and her colleagues (Thelen & Smith 1994) is rife with empirical evidence of this; some behaviors simply appear, that is, emerge as the child develops: "new forms of behavior can arise during development in a self-organizing manner, consistent with the universal laws of physics" (p. 129).

One major example of the emergence of complex behavior is that of language by human beings. Rumbaugh et al.'s (1996) analyses permit us at last to understand how this development may have come about in humans: the result of the dynamic interplay of biological and cultural evolution, as well as the contribution of ecologic factors (Greenberg, Partridge, Weiss, & Haraway, 1998). Although Skinner (1957) argued that human language development is the result of a long history of operant and respondent histories, it is, in fact, difficult to identify this historical sequence. Thus, though some, perhaps much, traditional learning may indeed be involved, the acquisition of language can be best understood as an emergent phenomenon, resulting from processes similar to those involved in proto-language acquisition by bonobos (Savage-Rumbaugh, Shanker, & Taylor, 1998)—the result of the dynamics involved in their unique social environment of almost constant interactions with their human caretakers. Parker and Russon (1996) identified common features shared by the great apes including prolonged gestation, infancy, and juvenile periods, a long developmental period, long life span, and a large brain. These features ally the apes to humans and distinguish them from gibbons and old world monkeys that show shorter gestation periods, shorter infancy and juvenile stages, shorter life spans, and smaller brains. Let us think of these elements as essential features, as components of a single dynamic system, much as hydrogen-oxygen-electricity are for the emergence of water. In our species, biological adaptations, socialization, and unique cultural experiences lead to a phase transition from protolanguage in chimpanzees and bonobos (and perhaps even in Neanderthals), to true language in our species.

Epigenetics and Epigenesis

I offer a quote that underscores the significance of new ways of thinking in molecular biology which call into question the central dogma of genetics (Crick, 1970), that genes alone account for phenotypes and work solely from the inside out. "Epigenetics is the most monumental explanation to emerge in the social and biological sciences since Darwin proposed his theories of natural selection and sexual selection" (Fisher, 2013, p. 179). Among the significant ideas of contemporary developmental science are those of epigenetics and epigenesis, first introduced into modern biology by Waddington in 1957 (Speybroeck, 2002), though as Valsiner and Scheithauer (2013) point out, "epigenetics antedates genetics" (p. 66). It took until modern times for the biological sciences to follow in Waddington's footsteps and understand the critical role that development plays in all aspects of biology, including evolution (Robert, 2004, 2008). Nevertheless, despite the renewed interest by some in studying development in an evolutionary framework (e.g., evolutionary-developmental biology [evo-devo]), "The field is still dominated by the idea that genes control development" (Ho, 2010, p. 70). Of course, the present authors, and others, believe instead that development itself is an epigenetic phenomenon from which novel processes emerge. A cogent discussion of this point is provided by Moore (2003).

These concepts supplement Darwinian evolution by showing that there are routes to inheritance other than by DNA and genetics. Epigenetics is the study of how the more than 200 human cell types can have an identical compliment of genes but express them differently. Part of the answer lies in the way that DNA is packaged, with tight areas silencing genes and open areas allowing for genes to be translated into proteins. *Epigenesis* refers to the influence of the environment on the expression of the genetic code. Among the best definitions of epigenesis for developmental science is that provided by Kuo (1967):

> We shall define behavioral epigenesis as a continuous developmental process from fertilization through birth to death, involving proliferation, diversification, and modification of behavior patterns both in space and in time, as a result of the continuous dynamic exchange of energy between the developing organism and its environment, endogenous and exogenous. The ontogenesis of behavior is a continuous stream of activities whose patterns vary or are modified in response to changes in the effective stimulation by the environment. (p. 11)

With respect to epigenesis, and especially its relation to the perspective I am discussing here, note that Overton (2011; Overton & Müller, 2012) follows in a long line of developmentally oriented scientists (e.g., Kuo, 1967; Moltz, 1965) in embracing the concept. His discussions reflect the breadth of his interests and his widespread impact on this discipline. Overton (2010) states that epigenesis

> is the principle that the role played by any part of a relational developmental system—gene, cell, organ, organism, physical environment, culture—is a function of all of the interpenetrating and coacting parts of the system. It is through complex relational bidirectional and multidirectional reciprocal interpenetrating actions among the coacting parts that the system moves to levels of increasingly organized complexity. . . . Epigenesis also points to a closely related feature of transformational developmental change: *emergence*. Transformational change results in the *emergence of system novelty*. (p. 7)

We know from the work of Gilbert Gottlieb (2004) that developmental outcomes are probabilistic, rather than predetermined, as the central dogma of genetic dictates. Events at all levels influence all phenotypic outcomes, structural as well as behavioral (see Lux, 2013); in other words, everything influences everything! Valsiner and Scheithauer (2013) referred to Gottlieb's model of probabilistic epigenesis as "bold." In an excellent article outlining corroborative findings of Gottlieb's model, Molenaar (2007) summed it up this way:

> It is a tribute to the genius of Gilbert Gottlieb that his key notion of probabilistic epigenesis and his profound critique of developmental behavior genetics, both integral parts of his theoretical work, find such strong corroboration in mathematical biology and mathematical statistics. (p. 142)

A key point in Gottlieb's probabilistic epigenesis is that phenotypic outcomes (behavioral and structural) are not due to genetic or environmental factors, but to the developmental process itself. Gottlieb, as had Waddington before him, understood that there was no one-to-one relation between a gene and a phenotypic character (Speybroeck, 2002). Then, as now, we recognize that genes work together to form gene networks (Slavich & Cole, 2013).

These ideas have evolved, as has our understanding of genetics, and especially just what genes are, or are not. "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" (Neuman-Held, 2001, p. 69). Indeed, since the development of the modern synthesis in mid-20th century, the very notion of just what a gene is has changed (Keller, 2002; Speybroeck, 2002). It is no longer sufficient to speak of "the" gene; the term has come to mean different things to different people. It may be that "gene" is not so much an identifiable "thing" as it 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 (Keller, 2002). In fact, "Up until 1962 it was problematic to physically identify one gene from another" (Speybroeck, 2002, p. 63), at the time genes lacking physical identity.

The larger point here is that through experimental studies of developing organisms, it has become clear that the conceptualization of the gene as held by the central dogma was untenable; it would not explain empirical findings. The genocentrism of developmental behavior genetics, long criticized by Gottlieb (Molenaar, 2007), is giving way to the model I favor in this article, RDS. Despite the hailed successes of the Human Genome Project, "it raised as least as many questions as it answered" (Masterpasqua, 2009, p. 194). No less a genetic scholar as Lewontin (2000) has also acknowledged that the impact of the Human Genome Project on our understanding of genetic influences on behavior was minimal (Lewontin, 2000).

CONCLUDING COMMENTS

I have tried to summarize in this article how some new ideas from biology and physics relate to developmental science, specifically to RDS theory, or what Lickliter (2013) more generally refers to as "Psychobiological systems theory" (p. 79). In doing so it was necessary to review essential concepts from contemporary physics, cosmology, and molecular biology. Thus, complexity, emergence, self-organization, behavior genetics, epigenesis, and epigenetics were briefly discussed. Nonlinear dynamic systems theory provides a theoretically consistent language with which to describe and analyze behavioral development. Nonlinear dynamics contains a lexicon of concepts pertaining to change processes over time that does not exist in any other known theoretical system. Dynamic models allow us to compare and contrast seemingly unrelated phenomena that often share common dynamical structures. Nonlinear dynamics and complex systems analysis are continuing to help revolutionize our understanding in many of the life sciences, though these ideas are just beginning to find their way into mainstream psychology and especially in developmental science. This situation was summarized by Stuart Kauffman (1993), a leading figure in the widespread application of these ideas as follows:

> Eighteenth-century science, following the Newtonian revolution, has been characterized as developing the sciences of organized simplicity, nineteenth-century science, via statistical mechanics, as focusing on disorganized complexity, and twentieth and twenty-first-century as confronting organized complexity. (p. 173)

Over the past few decades there has been a burgeoning of theoretical developments across a diverse set of disciplines including developmental psychology, sociology, developmental epidemiology, psychobiology, and embryology—in a word, developmental science (Bergman, Cairns, Nilsson, & Nystedt, 2000) that have a common conceptual foundation and methodological approach. Although these theoretical formulations may differ somewhat in their specifics, they share a core set of common assumptions such that Bronfenbrenner referred to these interdisciplinary advances as an "emergent convergence and isomorphism" (cited in Cairns, Elder, & Costello, 1996, p. ix). It is in this context that Rumbaugh's (Rumbaugh et al., 1996) proposals of "emergent learning" will play an important role in developmental science in coming generations.

I close with a set of apt quotations, statements that demonstrably link psychology and developmental science with theoretical developments in science in general:

> We know that our universe obeys simple low-level rules—laws of nature, including rules for subatomic particles and for space and time. We also know that life behaves in ways that do not seem to be built explicitly into those rules. Life is flexible; life is free; life seems to transcend the rigidity of its physical origins. This kind of transcendence is called "emergence." Emergence is not the absence of causality; rather it is a web of causality so intricate that the human mind cannot grasp it. We cannot understand how a frog works by listing the movement of every atom in it. In some sense, the atoms are the cause of the frog's behavior–but that's a totally useless way to approach frog biology. In order to understand the deeper significance of life we need an effective theory of emergent features. (Stewart, 2002, pp. 7–8)

Additionally, I refer to comments by Goldstein (1999), though made 14 years ago are still pertinent to the current discussion:

> An appeal to emergence is thus a way to describe the need to go to the macro level and its unique dynamics, laws, and properties in order to explain what is going on. The construct of emergence is therefore only a foundation on which to build an explanation, not its terminus. (p. 58)

> Finally, there is the fact that complexity science is only in its infancy. As it matures, better quantitative tools will be coming forth that offer richer ways of studying emergent phenomena. (p. 68)

And finally, reinforcing the "newness" of these ideas is this assessment by Waldrop (1992): "the science of *complexity*—a subject that's still so new and so wide-ranging that nobody knows quite how to define it, or even where its boundaries lie" (p. 9).

REFERENCES

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, CA: Freeman.

Anderson, P. W. (1972). More is different. *Science*, *177*, 393–396.

Bateson, P., & Curley, J. (2013). Developmental approaches to behavioural biology. *Nova Acta Leopoldina NF 111*, *380*, 89–110.

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.

Beins, B. C. (2012). Is psychology the other-than-science science? *Psychology Teacher Network*. Retrieved from http://www.apa.org/ed/precollege/ptn/2012/08/other-science.aspx

Bergman, L. R., Cairns, R. B., Nilson, L.-G., & Nystedt, L. (2000). *Developmental science and the holistic approach*. Mahwah, NJ: Erlbaum.

Bertalanffy, L. Von. (1956). A biologist looks at human nature. *Scientific Monthly*, *82*(1), 33–41.

Blumberg, M. (2005). *Basic instinct: The genesis of behavior*. New York, NY: Thunder's Mouth Press.

Boorstein, D. J. (1998). *The seekers*. New York, NY: Vintage.

Boring, E. G. (1950). *A history of experimental psychology* (2nd ed.). New York, NY: Appleton-Century-Crofts.

Boyack, K. W., Klavans, R., & Borner, K. (2005). Mapping the backbone of science. *Scientometrics*, *64*, 351–374.

Brunswick, E. (1956). Historical and thematic relations of psychology to other sciences. *Scientific Monthly*, *83*(3), 151–161.

Bunge, M. (1977). Levels of reduction. *American Journal of Physiology*, *233*(3), R75-R82.

Cairns, R. B., Elder, G. H., & Costello, J. (1996). *Developmental science*. New York, NY: Cambridge University Press.

Chaisson, E. J. (2001). *Cosmic evolution: The rise of complexity in nature*. Cambridge, MA: Harvard University Press.

Charney, E. (2012). Behavior genetics and post genomics. *Behavioral and Brain Sciences*, *35*(6), 1–80.

Chorover, S. L. (1990). Paradigms lost and regained: Changing beliefs, values, and practices in neuropsychology. In G. Greenberg & E. Tobach (Eds.), *Theories of the evolution of knowing* (pp. 87–106). Hillsdale, NJ: Erlbaum.

Christakis, N. A. (2013, July 21). Let's shake up the social sciences. *The New York Times*, p. SR12.

Christian, D. (2013). The idea of emergence. In J. Brockman (Ed.), *This explains everything: Deep, beautiful, and elegant theories of how the world works* (pp. 174–176). New York, NY: Harper/Perennial.

Coveny, P., & Highfield, R. (1995). *Frontiers of complexity: The search for order in a chaotic world*. London, UK: Faber and Faber.

Crick, F. (1970). Central dogma of molecular biology. *Nature*, *227*, 561–563.

Davies, P. (2003a). Complexity and the arrow of time. In N. H. Gregersen (Ed.), *From complexity to life: On the emergence of life and meaning* (pp. 72–92). Oxford, UK: Oxford University Press.

Davies, P. (2003b). Introduction: Toward an emergentist worldview. In N. H. Gregersen (Ed.), *From complexity to life: On the emergence of life and meaning* (pp. 3–16). Oxford, UK: Oxford University Press.

Davies, P., & Gribbin, J. (1992). *The matter myth*. New York, NY: Simon & Schuster.

Feibleman, J. K. (1954). Theory of integrative levels. *British Journal for the Philosophy of Science*, *5*, 59–66.

Fisher, H. (2013). Epigenetics – the missing link. In J. Brockman (Ed.), *This explains everything: Deep, beautiful, and elegant theories of how the world works* (pp. 179–182). New York, NY: Harper/Perennial.

Ford, D. H., & Lerner, R. M. (1992). *Developmental systems theory: An integrative approach*. Newbury Park, CA: Sage Publications.

Glick, J. A. (1992). Werner's relevance for contemporary developmental psychology. *Developmental Psychology*, *28*, 558–565.

Goldstein, J. (1999). Emergence as a construct: History and issues. *Emergence*, *1*, 49–72.

Goodwin, B. (1994). *How the leopard got its spots: The evolution of complexity*. New York, NY: Scribner's.

Gottlieb, G. (1973). Introduction to behavioral embryology. In G. Gottlieb (Ed.), *Studies on the development of behavior and the nervous system: Vol. 1. Behavioral embryology* (pp. 3–45). New York, NY: Academic Press.

Gottlieb, G. (1984). Evolutionary trends and evolutionary origins: Relevance to theory in comparative psychology. *Psychological Review*, *91*, 448–456.

Gottlieb, G. (1985). Anagenesis: Theoretical basis for the ecological void in comparative psychology. In T. D. Johnston & A. T. Pietrewicz (Eds.), *Issues in the ecological study of learning* (pp. 59–72). Hillsdale, NJ: Erlbaum

Gottlieb, G. (1992). *Individual development and evolution: The genesis of novel behavior*. New York, NY: Oxford University Press.

Gottlieb, G. (2001). The relevance of developmental-psychobiological metatheory to developmental neuropsychology. *Developmental Neuropsychology*, *19*, 1–9.

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.

Greenberg, G. (2008). Psychology from the standpoint of an interbehaviorist. Extended review of *J. R. Kantor and interbehaviorism. Psychological Record*, *58*, 665–676.

Greenberg, G. (2011). The failure of biogenetic analysis in psychology: Why psychology is not a biological science. *Research in Human Development*, *8*, 173–191.

Greenberg, G., Callina, K. S., & Mueller, M. K. (2013). Emergence, self-organization and developmental science. In R. M. Lerner & J. B. Benson (Eds.), *Embodiment and epigenesis: Theoretical and methodological issues in understanding the role of biology within the relational developmental system. Part A: Philosophical, theoretical, and biological dimensions* (pp. 95–126). Waltham, MA: Elsevier Inc. Academic Press

Greenberg, G., & Haraway, M. H. (2002). *Principles of comparative psychology*. Boston, MA: Allyn & Bacon.

Greenberg, G., & Partridge, T. (2010). Biology, evolution, and development. In W. F. Overton (Ed.), *Handbook of life-span development*: *Vol. 1. Cognition, biology, and methods* (pp. 115–148). Hoboken, NJ: Wiley.

Greenberg, G., Partridge, T., Mosack, V., & Lamdbin, 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.

Greenberg, G. & Tobach, E. (Eds.). (1984). *Behavioral evolution and integrative levels*. Hillsdale, New Jersey: Lawrence Erlbaum.

Hatfield, G. (1995). Remaking the science of mind: Psychology as natural science. In C. Fox, R. Porter, & R. Wolker (Eds.), *Inventing human science: Eighteenth-century domains* (pp. 184–231). Berkeley, CA: University of California Press.

Hatfield, G. (2000). The brain's "new" science: Psychology, neurophysiology, and constraint. *Philosophy of Science*, *67*, S388–S403.

Hatfield, G. (2003). Psychology: Old and new. In T. Baldwin (Ed.), *The Cambridge history of philosophy 1870-1945* (pp. 93–106, 823–827). Cambridge, UK: Cambridge University Press.

Ho, M. W. (2010). Development and evolution revisited. In K. E. Hood, C. T. Tucker, G. Greenberg, & R. M. Lerner (Eds.), *Handbook of developmental science, behavior, and genetics* Malden, MA: Wiley-Blackwell.

Hood, K. E., Tucker Halpern, C., Greenberg, G., & Lerner, R. M. (Eds.). (2010). *Handbook of developmental science, behavior, and genetics*. Malden, MA: Wiley-Blackwell.

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, IL: Principia Press.

Kauffman, S. A. (1993). *The origins of order: Self-organization and selection in evolution*. New York, NY: Oxford University Press.

Kauffman, S. A. (2008). *Reinventing the sacred: A new view of science, reason and religion*. New York, NY: Basic Books.

Keller, E. F. (2002). *Making sense of life: Explaining biological development with models, metaphors, and machines*. Cambridge, MA: Harvard University Press.

Koopmans, M. (2009). Epilogue: Psychology at the edge of chaos. In S. J. Guastello, M. Koopsmans, & D. Pincus (Eds.), *Chaos and complexity in psychology: The theory of nonlinear dynamical systems* (pp. 506–526). New York, NY: Cambridge University Press.

Kuo, Z.-Y. (1967). *The dynamics of behavior development*. New York, NY: Random House.

Lazar, J. (1978). A comparison of some theoretical proposals of J. R. Kantor and T. C. Schneirla. *Psychological Record*, *24*, 177–190.

Lehrman, D. S. (1953). A critique of Konrad Lorenz's theory of instinctive behavior. *Quarterly Review of Biology*, *28*(4), 337–363.

Lerner, R. M. (1995). The integration of levels and human development: A developmental contextual view of the synthesis of science and outreach in the enhancement of human lives. In. K. E. Hood, G. Greenberg, & E. Tobach (Eds.), *Behavioral development: Concepts of approach/withdrawal and integrative levels (Essays from the 5th T. C. Schneirla Conference)* (pp. 421–446). New York, NY: Garland Publishing.

Lerner, R. M. (1998). Developmental contextualism. In G. Greenberg & M. M. Haraway (Eds.), *Comparative psychology: A handbook* (pp. 88–97). New York, NY: Garland/Taylor & Francis.

Lerner, R. M. (2002). Multigenesis: Levels of professional integration in the life span of a developmental scientist. In D. J. Lewkowick & R. Lickliter (Eds.), *Conceptions of development: Lessons from the laboratory* (pp. 313–337). New York, NY: Psychology Press.

Lerner, R. M. (2006). Developmental science, developmental systems, and contemporary theories of human development. In R. M. Lerner (Ed.), *Handbook of child psychology. Vol. 1. Theoretical models of human development* (6th ed., pp. 1–17). New York, NY: Wiley.

Lerner, R. M., & Benson, J. B. (2013). Introduction: Embodiment and epigenesis: A view of the issues. In R. M. Lerner & J. B. Benson (Eds.), *Embodiment and epigenesis: Theoretical and methodological issues in understanding the role of biology within the relational developmental system Part A: Philosophical, theoretical, and biological dimensions* (pp. 1–20). Waltham, MA: Elsevier Inc. Academic Press.

Lerner, R. M., & Bush-Rossnagel, N. A. (1981). Individuals as producers of their development: Conceptual and empirical issues. In R. M. Lerner & N. A. Bush-Rossnagel (Eds.), *Individuals as producers of their development: A life-span perspective* (pp. 1–36). New York: Academic Press.

Lewontin, R. (2000). *It ain't necessarily so: The dream of the human genome and other illusions*. New York, NY: New York Review Books.

Lickliter, R. (2013). Modeling psychobiological development in the post-genomic era. *International Journal of Developmental Science*, *7*, 79–82.

Lux, V. (2013). With Gottlieb beyond Gottlieb: The role of epigenetics in psychobiological development. *International Journal of Developmental Science*, *7*, 69–78.

Mabry, P. L., & Urban, J. B. (Eds.). (2011). Embracing Systems Science: New Methodologies for Developmental Science [Special Issue]. *Research in Human Development*, *8*(1).

Mahner, M., & Bunge, M. (1997). *Foundations of biophilosophy*. Berlin, Germany: Springer.

Masataka, N. (1994). Effects of experience with live insects on the development of fear of snakes in squirrel monkeys, *Saimiri sciurens. Animal Behaviour*, *46*, 741–746.

Masterpasqua, F. (2009). Psychology and epigenetics. *Review of General Psychology*, *13*, 194–201.

McLaughlin, B. P. (2008). Emergence and supervenience. In M. A. Bedau & P. Humphreys (Eds.), *Emergence: Contemporary readings in philosophy and science* (pp. 81–97). Cambridge, MA: MIT Press.

McShea, D. W., & Brandon, R. N. (2010). *Biology's first law: The tendency for diversity and complexity to increase in evolutionary systems*. Chicago, IL: University of Chicago Press.

Michel, G. F. (2007). Doing what comes naturally: The role of self generated experience in behavioral development. *European Journal of Developmental Science*, *1*, 155–164.

Michel, G. F. (2013). The role of developmental psychobiology in the unification of psychology. *Review of General Psychology*, *17*, 210–215.

Molenaar, P. C. M. (2007). Developmental systems theory contra developmental behavior genetics. Gilbert Gottlieb, in memoriam. *European Journal of Developmental Science*, *1*, 138–143.

Molenaar, P. C. M. (2010). On the limits of standard quantitative genetic modeling of inter-individual variation: Extensions, ergotic conditions and a new genetic factor model of intra-individual variation. In K. E. Hood, C. T. Halpern, G. Greenberg, & R. M. Lerner (Eds.), *Handbook of developmental science, behavior, and genetics* (pp. 626–648). Malden, MA: Wiley-Blackwell.

Moltz, H. (1965). Contemporary instinct theory and the fixed action pattern. *Psychological Review*, *72*, 27–47.

Moore, C. (2003). Evolution, development, and the individual acquisition of traits: What we've learned since Baldwin. In B. H. Weber & D. J. Depew (Eds.), *Evolution and learning: The Baldwin effect reconsidered* (pp. 115–139). Cambridge, MA: MIT Press.

Nagel, T. (2012). *Mind and cosmos: Why the materialist neo-Darwinian conception of nature is almost certainly false*. Oxford, UK: Oxford University Press.

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.

Nicolis, G. (1989). Physics of far-from-equilibrium systems and self-organisation. In P. Davies (Ed.), *The new physics* (pp. 316–347). Cambridge, UK: Cambridge University Press.

Novikoff, A. (1945). The concept of integrative levels and biology. *Science*, *101*, 209–215.

Oparin, A. I. (1961). *Life: Its nature, origin and development*. New York, NY: Academic Press.

Overton, W. F. (1994). The arrow of time and the cycle of time: Concepts of change, cognition, and embodiment. *Psychological Inquiry*, *5*(3), 215–237.

Overton, W. F. (2010). Life span development: Concepts and issues. In W. F. Overton (Ed.), *Cognition, biology, and methods. Volume 1 of the Handbook of life-span development* (pp. 1–29). Hoboken, NJ: Wiley.

Overton, W. F. (2011). Relational developmental systems and quantitative behavior genetics: Alternative or parallel methodologies? *Research in Human Development*, *8*, 258–263.

Overton, W. F. (2012). Evolving scientific paradigms: Retrospective and prospective. In L. L'Abate (Ed.), *Paradigms in theory construction* (pp. 31–68). New York, NY: Springer.

Overton, W. F. (2013). Relationism and relational-developmental-systems: A paradigm for developmental science in the post-Cartesian era. In R. M. Lerner & J. B. Benson (Eds.), *Advances in child development and behavior, Vol. 44. Embodiment and epigenesis: Theoretical and methodological issues in understanding the role of biology within the relational developmental system* (pp. 21–64). Waltham, MA: Elsevier Inc. Academic Press.

Overton, W. F., & Lerner, R. M. (2012). Relational developmental systems: A paradigm for developmental science in the post genomic era. *Behavioral and Brain Sciences*, *35*(5), 375–376.

Overton, W. F., & Müller, U. (2012). Meta-theories, theories, and concepts in the study of development. In R. M. Lerner, M. A. Esterbrooks, & J. Misatry (Eds.), *Comprehensive handbook of psychology*: *Developmental psychology* (Vol. 6, 2nd ed., pp. 19–58). New York, NY: Wiley.

Parker, S. T., & Russon, A. E. (1996). On the wild side of culture and cognition in the great apes. In A. E. Russon, K. A. Bard, & S. T. Parker (Eds.), *Reaching into thought: The minds of the great apes* (pp. 430–450). Cambridge, UK: Cambridge University Press.

Pronko, N. H. (1980). *Psychology from the standpoint of an interbehaviorist*. Monterey, CA: Brooks/Cole.

Pronko, N. H. (1988). Heredity versus environment. In N. H. Pronko (Ed.), *From AI to Zeitgeist: A philosophical guide for the skeptical psychologist* (pp. 75–80). New York, NY: Greenwood Press.

Reid, R. G. B. (2007). *Biological emergences: Evolution by natural experiment*. Cambridge, MA: MIT Press.

Robert, J. S. (2004). *Embryology, epigenesis, and evolution: Taking development seriously*. Cambridge, UK: Cambridge University Press.

Robert, J. S. (2008). Taking old ideas seriously: Evolution, development, and human behavior. *New Ideas in Psychology*, *26*, 387–404.

Rumbaugh, D. M., Washburn, D. A., & Hillix, W. A. (1996). Respondants, operants and emergents: Toward an integrated perspective on behavior. In K. Pribram & J. King (Eds.), *Learning as a self-organizing process* (pp. 57–73). Hillsdale, NJ: Erlbaum.

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 of complexity in evolution II. The relativity of complexity and the principle of minimum increase. *Journal of Theoretical Biology*, *90*, 515–530.

Saunders, P. T., & Ho, M.-W. (1984). The complexity of organisms. In J. W. Pollard (Ed.), *Evolutionary theory: Paths into the future* (pp. 121–139). New York, NY: Wiley.

Savage-Rumbaugh, S., Shanker, S. G., & Taylor, T. J. (1998). *Apes, language, and the human mind*. New York, NY: Oxford University Press.

Sawyer, R. K. (2002). Emergence in psychology: Lessons from the history of non-reductionist science. *Human Development*, *45*, 2–28.

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, NY: Macmillan.

Singh, S. (2004). *Big bang*. New York, NY: Harper Collins.

Skinner, B. F. (1957). *Verbal behavior*. New York, NY: Appleton-Century-Crofts.

Slavich, G. M., & Cole, S. W. (2013). The emerging field of social genomics. *Clinical Science*, *1*(3), 331–348.

Speybroeck, L. V. (2002). From epigenesis to epigenetics. The case of C. H. Waddington. *Annals of the New Psychological York Academy of Science*, *981*, 61–81.

Stewart, I. (2002). *Life's other secret: The new mathematics of the living world*. New York: John Wiley & Sons.

Thelen, E., & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action*. Cambridge, MA: MIT Press.

Urban, J. B., Osgood, N. D., & Mabry, P. L. (2011). Developmental systems science: Exploring the application of systems science methods to developmental science questions. *Research in Human Development*, *8*(1), 1–25.

Uttal, W. R. (2005). *Neural theories of mind: Why the mind-brain problem may never be solved*. Mawah, NJ: Erlbaum.

Uttal, W. (2011). *Mind and brain: A critical appraisal of cognitive neuroscience*. Cambridge, MA: MIT Press.

Valsiner, J. (2005a). General introduction: Developmental science in the making of the role of Heinz Werner. In J. Valsiner (Ed.), *Heinz Werner and developmental science* (pp. 1–17). New York: Kluwer Academic/Plenum Publishers.

Valsiner, J. (Ed.). (2005b). *Heinz Werner and developmental science*. New York: Kluwer Academic/Plenum Publishers.

Valsiner, J., & Scheithauer, H. (2013). Epigenetic innovations for developmental science. *International Journal of Developmental Science*, *7*, 65–67.

Van der Veer, R. (2005). The making of a developmental psychologist. In J. Valsiner (Ed.), *Heinz Werner and developmental science* (pp. 75–105). New York: Kluwer Academic/Plenum Publishers.

Van Geert, P. (2009). Nonlinear complex dynamical systems in developmental psychology. In S. J. Guastello, M. Koopsmans, & D. Pincus (Eds.), *Chaos and complexity in psychology: The theory of nonlinear dynamical systems* (pp. 242–281). New York, NY: Cambridge University Press.

Waldrop, M. M. (1992). *Complexity: The emerging science at the edge of order and chaos*. New York, NY: Simon and Schuster.

Wahlsten, D. (2012). The hunt for gene effects pertinent to behavioral traits and psychiatric disorders: From mouse to human. *Developmental Psychobiology*, *54*, 475–492.

Werner, H. (1948). *The comparative psychology of mental development* (Rev. ed.). New York, NY: International Universities Press.

Witherington, D. C. (2007). The dynamic systems approach as metatheory for developmental psychology. *Human Development*, *50*, 127–153.

Witherington, D. C. (2011). Taking emergence seriously: The centrality of circular causality for dynamic systems approaches to development. *Human Development*, *54*, 66–92.

Woodger, J. H. (1929). *Biological principles: A critical study* (2nd ed.). London, UK: Routledge.