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## SCIENCE AT THE CROSSROADS

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### Evolution: The Public's Problem, and the Scientists'

*Stuart A. Newman*

The fact that organic evolution occurred, and continues to occur, is as solid as any conclusion science has yet produced. To take issue with this, considering the interconnected biological, chemical, geological, and physical facts that enter into our knowledge of evolution, is to take issue with much of modern science. Significantly, though, many people throughout the world, particularly in the United States, continue to reject a naturalistic account of the origination of complex biological systems and the genesis of species.

Skepticism about evolution appears to be based more on received views influenced by religious belief than on the persuasive force of contemporary anti-evolution counter-narratives. Nonetheless, several current schools of thought seek to capitalize on inadequacies or flaws in various versions of the account of mainstream biology.<sup>1</sup> "Young earth creationism," for example, pointing to gaps in the fossil record, adheres closely to Biblical accounts of the genesis of the world and its life forms, holding that life was established on Earth around 6,000 years ago. The more recently established "Intelligent Design" movement, in contrast, accepts the age of the Earth as determined by science and even a role for evolution in molding many biological features (e.g., the overall structure of the bodies and appendages of insects, humans, and other many-celled organisms) but asserts that other, finer features, such as the microscopic beating whip on the surface of cells known as the flagellum, are "irreducibly complex" and can only have been generated by a "designer" located outside the frame of naturalistic thought.<sup>2</sup>

The take on this by the secular liberal mainstream is that it represents a rejection of rationalism. However, few contemporary religionists, even the most fundamentalist of them, question mechanistic and other naturalistic accounts of *observable* phenomena. This is clearly a departure from ancient cultures where animistic explanations of things like fire and the weather were standard. Nor do most religious believers in the developed world reject medicines and surgical procedures based on

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<sup>1</sup>See Eugenie C. Scott, *Evolution vs. Creationism: An Introduction* (Westport, CT: Greenwood Press, 2004).

<sup>2</sup>Michael J. Behe, *The Edge of Evolution: The Search for the Limits of Darwinism* (New York: Free Press, 2007).

the conception of the living human organism as a physical and chemical entity. And whatever they may think about how the cell's flagellum originated, the idea that the motion of this structure occurs by standard physicochemical processes is uncontroversial to the vast majority of religionists.

Why then, do so many people reject an evolutionary account of complex biological systems? First, we must recognize that in contemplating the origins of the world as we know it, most members of even advanced technological societies, including a fair number of scientists and philosophers, are comfortable bringing supernatural causation into the picture at some point, particularly in the distant past.<sup>3</sup> So it is not simply a matter of who believes in science and who believes in divine intervention (most people seeming to believe in an amalgam of the two), but whether the scientific narrative on offer is persuasive enough to force people to reevaluate and possibly abandon their received worldview.

Second, for most people, their experienced life is more important to them than what occurred 3 billion (or even 6,000) years ago. People's experience of organismal types—wild and domestic animals and plants—focuses on, and indeed depends on, the constancy of the species' identities, not the possibility that they are on their way to changing into something else.<sup>4</sup> And, other than perhaps for existentialist philosophers and constitutional cynics, the feeling that life is fundamentally meaningless is usually a source of unhappiness. It should therefore not be expected that secularist jibes, such as the recent essay in *The Guardian* on the evolution wars by the environmental writer George Monbiot titled "A Life with No Purpose," would be effective in recruiting the general citizenry to an evolutionary perspective. The gist of this article is contained in the following passages:

[A]s soon as you consider the implications [of Darwin's theory], you must cease to believe that either Life or life are affected by purpose . . . Darwinian evolution tells us that we are incipient compost: assemblages of complex molecules that—for no greater purpose than to secure sources of energy against competing claims—have developed the ability to speculate. After a few score years, the molecules disaggregate and return whence they came. Period.<sup>5</sup>

Such ultimate questions are, of course, irrelevant to the criteria that most people (including historical materialists and social revolutionaries) use in judging whether

<sup>3</sup>Among these are the physicist Freeman Dyson; Francis Collins, the director of the U.S. government's Human Genome Project; and the philosopher of science, Michael Ruse. A resource for the views of religion-friendly scientists and philosophers, as well as those of some nonbelievers, is "Meaning of Life TV" (<http://meaningoflife.tv>), a series of video interviews by Robert Wright on Slate.com.

<sup>4</sup>The title of the manuscript sent by Alfred Russel Wallace to Charles Darwin in 1858, spurring the latter's publication of his own, similar, theory of evolution, was "On the Tendency of Varieties to Depart Indefinitely from the Original Type," *Proceedings of the Linnean Society of London*, Vol. 3, 1858, p. 53. The malleability of organismal type, despite experience to the contrary, remains a tenet of the neo-Darwinian synthesis.

<sup>5</sup>George Monbiot, "A Life Without Meaning," *The Guardian*, August 16, 2005.

their lives and actions are meaningful. Moreover, Darwinism itself, which concerns populations of organisms, not molecules, has nothing at all to do with these issues, except in an ideological sense (see below). The failure to persuade of thumbs-in-the-eye like Monbiot's, or similar ones by such arch-Darwinists as Richard Dawkins,<sup>6</sup> is therefore not surprising, and this is not just a matter of the obduracy of fundamentalists.

The program of advancing materialism against supernaturalism and superstition is clearly a necessary one. But in making the case for a scientific narrative of ancient events with people who do not have a big incentive to relinquish what their parents and churches have told them, it is helpful at least to have a persuasive theory of how life forms and how the characteristics of individual organisms originated. Does Darwin's theory of evolution by natural selection meet this standard?

The answer is a mixed one. Incremental changes in an existing biological structure—the alterations in beak shape of the finches that so impressed Charles Darwin during his voyage to the Galapagos Islands, for instance—can indeed be attributed to natural selection. Even most creationists do not deny this. But when it comes to the *innovation* of entirely new structures (“morphological novelties”) such as segmentally organized bodies (seen in earthworms, insects, and vertebrates such as humans, but not jellyfish or molluscs), or the hands and feet of tetrapods (vertebrates with four limbs), Darwin's mechanism comes up short. This is a reality that is increasingly acknowledged by biologists, particularly those working in the field of evolutionary developmental biology, or “EvoDevo.”

Contrary to the expectations of the Darwinian model, the fossil record is deficient in transitional forms between organisms distinguished from one another by the presence or absence of major innovations. Niles Eldredge and the late Stephen Jay Gould emphasized this point when they propounded their scenario of “punctuated equilibria” almost four decades ago.<sup>7</sup> And although our current knowledge of the cellular and genetic mechanisms of the development of animal forms is relatively sophisticated, it is difficult to come up with plausible scenarios involving incremental changes in developmental processes that would take an organism from one adult form (e.g., an unsegmented worm) to one embodying an innovation (a segmented worm).

While evolutionary innovation is therefore a conspicuous problem for Darwinian gradualism, more satisfactory scientific accounts of this process have emerged from recent work in developmental biology. Significantly, these alternatives do not conform to the notion that form and structure in the living world result from

<sup>6</sup>Richard Dawkins, *The God Delusion* (Boston: Houghton Mifflin Co., 2006).

<sup>7</sup>Niles Eldredge and Stephen J. Gould, “Punctuated Equilibria: An Alternative to Phyletic Gradualism,” in Thomas J.M. Schopf (ed.), *Models in Paleobiology* (San Francisco: Freeman Cooper, 1972), pp. 82–115.

a purely opportunistic process of culling among random variants, a doctrine Gould called “Darwinian fundamentalism.”<sup>8</sup>

The example of segmentation in vertebrates illustrates the scientifically more incisive view of innovation that is currently emerging from evolutionary developmental biology. Living tissues are physical materials, albeit highly complex ones. The idea that materials can undergo abrupt changes in organization due to their inherent physical properties is quite familiar from everyday experience: a violin string can vibrate or not, depending on minor differences in the tension under which it is held, and water can form waves or vortices depending on the directionality of minor agitations. Scientists have shown that in analogous fashion, certain networks of interacting genes and their effectors in embryonic tissues can act as “biochemical clocks,” which means that the levels of several of the proteins produced by the tissue fluctuate periodically with time. They are set to different times at different positions along the embryo, causing successive waves of the involved molecules to sweep across the length of the developing body from one end to the other. This affects tissue cohesion in a periodic fashion, thereby producing a spatial periodicity (i.e., segments) in the tissue.<sup>9</sup> Since a given molecular-genetic network can act as an oscillator or not, depending on tiny variations in the constituent genes and their products,<sup>10</sup> segmentation, as a morphological novelty, can therefore have emerged multiple times, in a relatively sudden fashion, from unsegmented ancestors of modern segmented animals.

Segmentation is just one example of how the origination of phenotypic novelties can be understood by taking account of the physical nature of developing systems. Others are the formation in aggregates of cells of layers, interior spaces, tubes, and branched structures, in particular, all the constructional features of animal bodies and their organs.<sup>11</sup> The capacity of certain materials, non-living as well as living, to assume preferred forms by virtue of their inherent physical properties is known as “self-organization.”<sup>12</sup> The nature of such processes is such that transitions between very different looking forms can be quite abrupt. Such effects are an increasingly prominent explanatory aspect of modern developmental biology.

<sup>8</sup>Stephen J. Gould, “Darwinian Fundamentalism,” *New York Review of Books*, Vol. 44, 1997, p. 34.

<sup>9</sup>Olivier Pourquié, “The Segmentation Clock: Converting Embryonic Time into Spatial Pattern,” *Science*, Vol. 301, 2003, p. 328.

<sup>10</sup>Tiny variations are, of course, what neo-Darwinism appeals to as well. But in this newer view, the inherent (often nonlinear) dynamical properties of the system the genes or gene products are part of can convert small molecular changes into global reorganization of activity or structure.

<sup>11</sup>Gabor Forgacs and Stuart A. Newman, *Biological Physics of the Developing Embryo* (Cambridge: Cambridge University Press, 2005).

<sup>12</sup>See, generally, Ilya Prigogine and Isabelle Stengers, *Order Out of Chaos: Man's New Dialogue with Nature* (Boulder, CO: New Science Library, 1984); and Forgacs and Newman, *op. cit.*, for applications of this concept to developing embryos.

Since living tissues are self-organizing physical materials, their forms and behaviors must be subject to forces and determinants apart from their genes. In other words, they must exhibit condition-dependent variability, a phenomenon also referred to as “phenotypic plasticity.” As a consequence, an organism’s anatomical and other properties and transitions between alternative forms, particularly at early stages in its evolution, are not uniquely determined by its genes.

The EvoDevo view of organismal innovation thus implies that disparate phenotypes inherent to an organism’s constitution at a given stage of its evolution can be alternatively triggered by minor genetic changes, or even environmental changes.<sup>13</sup> Natural selection has a role here, but it is a stabilizing one: by acting in an incremental fashion on these alternative developmental pathways, it can reinforce their realization and make them independent of the original triggers. The remarkable stability or “robustness” of the phenotype, particularly in animal species, against environmental change and even much genetic alteration (the “equilibria” of punctuated equilibria), is thought to be the result of this progressive evolutionary reinforcement of developmental trajectories, termed “canalization.”<sup>14</sup> In addition, if the self-organization of living tissues was efficacious in originating and innovating forms during early evolution (the “punctuations”), then the rapid burst of morphological evolution of animals that occurred more than half a billion years ago (the “Cambrian explosion”<sup>15</sup>) becomes much more understandable.<sup>16</sup>

Phenotypic plasticity, a relatively common property of developing organisms, which was appreciated by many 19<sup>th</sup> century biologists and which provided the basis for Jean-Baptiste Lamarck’s (generally mischaracterized and not entirely incorrect) pre-Darwinian evolutionary concepts, is only now reentering biology after becoming an all-but-taboo subject within evolutionary theory during the 20<sup>th</sup> century. Darwin’s theory, in holding that the competition between individuals marginally different from one another with respect to the small, inherited, morphological, physiological, or behavioral variations encountered in any natural population, has been sufficient to generate the entire array of biologically distinct types seen on the face of planet, avoided cases in which the same organism could take on different forms under different conditions. Indeed, a major impact of Darwin’s theory of evolution by natural selection was to marginalize the concept of phenotypic plasticity. Once the theory’s scientific hegemony was established, all phenomena that fit this description were consigned to a theoretical limbo.

<sup>13</sup>For examples, see Stuart A. Newman and Gerd B. Müller, “Epigenetic Mechanisms of Character Origination,” *Journal of Experimental Zoology B (Mol. Dev. Evol.)*, Vol. 288, 2000, p. 304; and Mary Jane West-Eberhard, *Developmental Plasticity and Evolution* (Oxford and New York: Oxford University Press, 2003).

<sup>14</sup>Conrad H. Waddington, “Canalization of Development and the Inheritance of Acquired Characters,” *Nature* Vol. 150, 1942, p. 563.

<sup>15</sup>Stephen J. Gould, *Wonderful Life* (New York: W.W. Norton, 1989).

<sup>16</sup>Stuart A. Newman, Gabor Forgacs, and Gerd B. Müller, “Before Programs: The Physical Origination of Multicellular Forms,” *International Journal of Developmental Biology*, Vol. 50, 2006, p. 289.

The other major scientific reason for the marginalization of the concept of plasticity was successes in applying the Mendelian paradigm. The 19<sup>th</sup> century monk, Gregor Mendel, in performing his remarkable experiments on various plants, carefully picked traits to study whose different versions were uniquely tied to alternative states of specific genes. Much genetic research in the first half of the 20<sup>th</sup> century, using a similar strategy, also identified strict gene-trait correlations (particularly with regard to simple biochemical pathways) in other organisms. This led to a deep-seated conviction that the Mendelian mode of inheritance was essentially applicable to all traits in all organisms at all stages of their evolutionary histories. But even Mendel himself, who cautiously described his most famous findings as “the law valid for peas,” did not suggest this, and it is demonstrably not the case.

The Mendelian paradigm deals with factors, or genes, that are associated with biological characters. As such, it focuses on the *logic* of intergenerational transmission of traits (the alternative forms of characters) rather than the *mechanisms* of character generation. When joined with Darwinism in the form of the “neo-Darwinian synthesis,” it gave rise to a theory of evolution concerned with little else than the distribution and fate of genes at the populational level. The supposed ability of changes in gene frequencies to account for the emergence of all significant features of living organisms is considered by the philosopher Daniel Dennett one of the most powerful ideas ever produced by science.<sup>17</sup>

Other strains of early 20<sup>th</sup> century biological science, propounded by such figures as the British theorist of the physical basis of form generation, D’Arcy W. Thompson, the Soviet evolutionary developmental biologist, B. Zavodovsky, the African-American reproductive biologist, E.E. Just, the Soviet geneticist, I.I. Schmalhausen, the British developmental geneticist, C.H. Waddington and the German-born U.S. developmental physiologist, Richard Goldschmidt, were, in contrast, not exclusively genocentric. These scientists sought to bridge the gap between inheritance and form by bringing physical, physiological and environmental determinants of organismal form into a more comprehensive “systems” approach to scientific understanding of developmental and evolutionary processes and phenomena and the connections among them.<sup>18</sup> During the emergence of gene-centered biology in mid-century, the quantitative techniques and computational methods for management of complexity that are required for the pursuit of systems biology were yet to be invented. Consequently, the successes of the Mendelian approach in its relevant domains undermined any motivation in the scientific mainstream to consider an expanded framework.

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<sup>17</sup>Daniel C. Dennett, *Darwin’s Dangerous Idea: Evolution and the Meanings of Life* (New York: Simon & Schuster, 1995).

<sup>18</sup>Far from denying the efficacy of natural selection, these biologists typically presented an expanded picture in which the role of selection in preserving and reinforcing successful, marginally distinctive phenotypes was complemented by the dynamics of developmental processes in generating novelties.

Cold War politics also played an important part in the nearly total suppression of the systems approach in mid to late 20<sup>th</sup> century biology in the United States and Western Europe. The adoption by the Soviet Union of the anti-Mendelian doctrine of Lysenkoism<sup>19</sup> in agriculture, and then research biology, and the purging of geneticists from the scientific institutes, presented a vivid example of the corruption of science by a centrally controlled political-economic system. The Soviet scientific managers had initially appealed to a theory of evolution that incorporated phenotypic plasticity, an approach that had a legitimate warrant in sophisticated post-Revolutionary philosophy of science.<sup>20</sup> And while the failures of Lysenkoist agricultural policy were hardly worse than those of the earlier Mendelism-inspired policies,<sup>21</sup> Soviet biology was severely damaged by Lysenkoism.

While the propagandistic uses made by the Soviet Union's critics of its descent into Lysenkoism thus had considerable force and effectiveness, the resulting distortion of Western biology by the consequent entrenchment of Mendelian exclusivity, with dismissal and even ridicule by mainstream scientists of alternative, "systems" views, is rarely noted. This way of thinking was so entrenched that despite the concrete accounts of developmental processes that began to emerge during the last decades of the 20<sup>th</sup> century (such as the segmentation example described above) employing conditionally acting physical mechanisms (e.g., cell-cell adhesion, molecular diffusion, chemical oscillation) in addition to genetic methodologies and mechanisms, the entire enterprise has nonetheless been portrayed—inaccurately—as the triumph of the Mendelian paradigm.<sup>22</sup>

The Soviet doctrine of Lysenkoism represented an ideological distortion of evolutionary biology that may be thought of as generic to top-down socialism: environmental determinism gone wild; living systems with no inherent nature other than a capacity to be molded to the aims of social managers. Although this view, like the political system that engendered it, has vanished, the genetic determinist ideology that it both rejected and gave new life to, in its parceling of life into separable, swappable—and most importantly, patentable—modules, comports well with the worldview of advanced capitalism. The nearly exclusive focus on genes to account for biological change at the levels of both individual development and large-scale evolution, like the cash nexus of market economies, collapses quality into quantity, life into symbol. In its drive to transform nature into an engine for the production of wealth via "better" crops and ecosystems, and ultimately "better" people, genes are

<sup>19</sup>This policy in the Soviet Union, from the 1930s through the mid-1960s, declared genetics a "bourgeois pseudoscience" and promoted non-genetic techniques, such as exposure of seeds to cold and fertilizers, to increase agricultural yields.

<sup>20</sup>B. Zavadovsky, "The 'Physical' and the 'Biological' in the Process of Organic Evolution," in Mikhail Bukharin (ed.), *Science at the Crossroads* (London: Frank Cass and Co., 1931), pp. 69–80.

<sup>21</sup>Richard Levins and Richard C. Lewontin, *The Dialectical Biologist* (Cambridge, MA: Harvard University Press, 1985).

<sup>22</sup>See, for example, the recent account by the Nobel laureate Christiane Nüsslein-Volhard, *Coming to Life. How Genes Drive Development* (New Haven: Yale University Press, 2006).

the preferred currency. What is missing is a coherent theoretical framework, a historical materialism of the evolution of developmental systems.

Such a theory, as indicated above, is beginning to take form within the field of evolutionary developmental biology, but its implication that living systems may resist reconfiguration according to commercial requirements makes it, for the dominant classes, an unattractive alternative to the reigning model at all educational levels and in the broader culture.<sup>23</sup> What is offered instead is an accounting of the distribution of gene variants in populations over time and space, plus the assertion that such gene changes fully explain evolutionary change (because what else is there?). Which qualitative features of an organism are changing over the course of evolution, which of these changes amount to minor variations in phenotype and which to morphological innovations, new species, or even new phyla, are not the charge of evolutionary theory conceived in this fashion. Dominating and appropriating rather than understanding and cooperating with natural systems motivates this one-dimensional view.<sup>24</sup>

Given neo-Darwinism's doctrine that genes determine all biological properties and that all evolutionary changes are thus reducible to genetic changes, it is not surprising, once genetic engineering became feasible in the 1980s, that genes also came to be seen as the medium by which biological characteristics could be transferred from one type of organism to another. The evolutionary biologist E.O. Wilson, for instance, quotes approvingly the following statement from a talk by the entomologist, Thomas Eisner:

A biological species, nowadays, must be regarded as more than a unique conglomerate of genes. As a consequence of recent advances in genetic engineering, it must be viewed also as a depository of genes that are potentially transferable. A species is not merely a hard-bound volume of the library of nature. It is also a loose-leaf book, whose individual pages, the genes, might be available for selective transfer and modification of other species.<sup>25</sup>

In a similar spirit, a recent news report in the journal *Nature*, focusing on a newly identified gene whose unknown function is, according to one of the scientists involved, a matter of "wild speculation," is titled "Homing In on the Genes for Humanity," simply because the gene has changed rapidly over the course of human evolution.<sup>26</sup>

<sup>23</sup>The absolute conflation by the science and educational mainstream of the facts of evolution with Darwin's theory of these phenomena can be seen in the strategy of the 2004 lawsuit against the Dover, Pennsylvania Board of Education's decree that the alternative of Intelligent Design be presented in the biology classroom. See the public television documentary "Judgment Day: Intelligent Design on Trial" (NOVA and Vulcan Productions, 2007).

<sup>24</sup>See Joel Kovel, *The Enemy of Nature: The End of Capitalism or the End of the World?* (London: Zed Books, 2002), for the connection between reductionist and dominationist discourses around natural systems.

<sup>25</sup>Edward O. Wilson, *The Diversity of Life* (Cambridge, MA: Belknap Press of Harvard University Press, 1992), p. 302.

<sup>26</sup>Kerri Smith, "Homing In on the Genes for Humanity," *Nature*, Vol. 442, 2006, p. 725.

This view of life ignores everything about the context-dependence of gene function within organisms, including the fact that the role of an identical gene in two different kinds of organisms, or in a given organism at two different stages of its evolutionary history, can vary dramatically. The scientific literature is replete with examples of genetically engineered bacteria, plants, mice, and farm animals having properties different from predicted ones.

The creationists, for their part, have smaller fish to fry. The presence and operation of highly complex, nanoscale molecular “machines” within the cell present additional challenges to neo-Darwinian incrementalist scenarios that are not obviously soluble by either classic chemistry or the physics of macroscale chemically active materials discussed above. Even Francis Crick, the co-discoverer of the structure of DNA, was not convinced that the conditions on the prebiotic Earth were compatible with the chemical evolution of the genetic material, suggesting instead scenarios of “panspermia,” the seeding of the Earth by life forms from other sites in the Universe.<sup>27</sup> This, of course, is question begging of the first order. But in the quarter-century since Crick first confronted these difficulties, increased knowledge of the complexity of the nanomolecular systems within the cell has only made the question of origination and innovation at this level more puzzling.

Rather than Intelligent Design’s credulous positing of a nanoengineer God, however, what is called for are new scientific principles of self-organization on the nanoscale. There are well-known precedents for new theories emerging to explain anomalous scientific observations. The structure of atoms, for example, as manifested in their interactions with light upon being heated, was completely enigmatic until Erwin Schrödinger and Werner Heisenberg developed the unprecedented and anti-intuitive laws of quantum mechanics, independently, in 1925. Before this, however, the best physicists of the early 20<sup>th</sup> century had the courage to acknowledge that the old ideas were not adequate to account for these phenomena. The present-day neo-Darwinists provide a poor contrast to this, insofar as they persist in the hand-waving consignment of all problematic aspects of the origination of complex subcellular entities to the putative universal mechanism of random variation and natural selection.

Derision of a traditionalist segment of the public for not immediately jumping into line with standard selectionist narratives (however far-fetched they may be), is not the answer here. The scientific mainstream should rightly be prevailing in the evolution debate, since the living world is manifestly a product of evolution. But it and its liberal advocates are so wedded to a neo-Darwinism that has effectively become the house philosophy of the market economy that they are barely holding on in their attempts to prevent naturalistic accounts of the history of life from being expunged from school curricula. Unless the discourse around evolution is opened up to scientific perspectives beyond Darwinism, the education of generations to come is at risk of being sacrificed for the benefit of a dying theory.

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<sup>27</sup>Francis Crick, *Life Itself: Its Origin and Nature* (New York: Simon and Schuster, 1981).