

SCIENCE AT THE CROSSROADS

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, there exist several schools of thought that represent themselves as scientific, which seek to capitalize on inadequacies or flaws in various versions of the account of mainstream biology. "Young earth creationism," for example, 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.

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 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. 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. 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.

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

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. 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 a purely opportunistic process of culling among random variants, a doctrine Gould called “Darwinian fundamentalism.”

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. 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. Scientists have shown that segmentation in the vertebrate body is based on such biochemical clocks. Successive waves of the involved molecules sweep across the length of the embryo from one end to the other, affecting tissue cohesion in a periodic fashion, thereby producing a spatial periodicity (i.e., segments) in the tissue. Since a given molecular-genetic network can act as an oscillator or not, depending on tiny variations in the constituent genes and their products, 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 that enter into animal bodies and their organs. 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.” Such effects are an increasingly prominent aspect of modern developmental biology.

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.” Another way of expressing this is that an organism’s properties, 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. In evolutionary terms, natural selection, acting in an incremental fashion on these alternative developmental pathways, 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.” 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”) becomes much more understandable.

Phenotypic plasticity, a relatively common property of developing organisms, which was appreciated by many 19th 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 20th century. Darwin’s theory, which holds 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 effect 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 the real phenomena that fit this description were consigned to a theoretical limbo.

The other major scientific reason for the marginalization of the concept of plasticity was successes in applying the Mendelian paradigm. The 19th 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 20th 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 all significant features of living organisms is considered by the philosopher Daniel Dennett one of the most powerful ideas ever produced by science.

Other strains of early 20th century biological science, represented by such figures as the British theorist of the physical basis of form generation, D’Arcy W. Thompson, the Soviet evolutionary developmental biologist, B. Zavadovsky, 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. 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.

Cold War politics also played an important part in the nearly total suppression of the systems approach in mid to late 20th century biology in the United States and Western Europe. The adoption by the Soviet Union of the anti-Mendelian doctrine of Lysenkoism 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 command economy. 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. And while the failures of Lysenkoist agricultural policy were hardly worse than those of the earlier Mendelism-inspired policies, Soviet biology was severely damaged by Lysenkoism.

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

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 reacted to and stimulated 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 the preferred currency. What is missing from this is a valid theoretical framework, a historical materialism of the evolution of developmental systems.

Such a theory, as indicated above, is beginning to take form, 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. 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.

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.

More recently, a 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.

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 water-phase 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. 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. The best physicists of the early 20th 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, insofar as they persist in the hand-waving consignment of all problematic aspects of the origination of complex subcellular entities to the putative universal solvent of random variation and natural selection.

Derision of a traditionalist segment of the public for not immediately jumping into line with standard evolutionary 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.