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Renatured Biology:
Getting Past Postmodernism in the Life Sciences

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> We must consider the possibility that at some point in the future, different groups of human beings may follow divergent paths of development through the use of genetic technology. If this occurs, there will be different groups of beings, each with its own "nature," related to one another only through a common ancestor (the human race). . . . For all we know . . . they might not treat each other as moral equals.
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> —Allen Buchanan et al. (2000), *From Chance to Choice: Genetics and Justice*

Charles Darwin was a "naturalist," as were the other post-Enlightenment founders of modern biology: Carl Linnaeus, Georges-Louis Leclerc, Comte de Buffon, Gregor Mendel, Matthias Schleiden, and Theodor Schwann, to name only a few. The term was still a job description less than a century ago, when the collected works and a brief biography of William Bateson, the British scientist who introduced Mendel's ideas to the English-speaking world and coined the term "genetics," were published under the title *William Bateson, Naturalist*.[1] These days, however, there are few notions more derided by contemporary gene-centered biology and its commercial offshoots than "nature" and "the natural." The term is sometimes handled by bioethicists and policy analysts, but then only with rubber gloves. In a recent policy forum in the journal *Science* a group of twenty-two bioethicists, philosophers, and biologists addressed the question of the morality of introducing human brain tissue into the heads of nonhuman primates, first dispensing with distractions: "We unanimously rejected ethical objections grounded on unnaturalness or crossing species boundaries. Whether it is possible to draw a meaningful distinction between the natural and the unnatural is a matter of dispute."[2]

It is safe to assume that the biologists among the report's authors were not the ones who first formulated this position—an irate literature records the judgment of mainstream science on the purported social construction of empirical distinctions.[3] Nonetheless, echoing an assertion in a

1999 report by the British Nuffield Council on Bioethics that "[t]he 'natural/unnatural' distinction is one of which few practicing scientists can make much sense," the *Science* article's half-dozen basic and clinical scientist authors did in fact sign onto a statement that the distinction between the natural and the artifactual is irrelevant in considering the ethical implications of animals cobbled together from more than one species.[4]

Nature, in the sense of a world neither made nor influenced by human activity, is fundamental to any conception of science. In particular, there was a world before there were humans, and while much of it has been transformed, much has not: the structure of atoms, the Earth's topography, the anatomical plans and physiology of most organisms, the distinctness of biological species. Questions as to what extent (if at all) technologically untransformed nature represents a positive value and in which domains the natural and the artifactual become inextricable, are all, of course, "matters of dispute." That there is a conceptual difference between the natural and the human-made is not.[5] Indeed, Keekok Lee, in her remarkable book *The Natural and the Artefactual*, distinguishes seven different senses of "nature," several of which she argues are loci of values jeopardized by certain technological activities.[6]

As evidenced by the comments quoted above from the Nuffield Council Report and the *Science* article, however, since the 1980s, along with the emergence of genetic methodologies capable of transforming the material character of biological systems, radically skeptical assertions of the meaninglessness of the distinction between the natural and artifactual have been made by an increasingly vocal group of bioethicists and science writers.[7] Though representing itself as the carrier and defender of a liberating and opportunity-laden technological culture, this movement, which I refer to as "biological postmodernism," is instead, I argue, traducing the most incisive findings of contemporary biological science while enabling commercial forces to fashion a world where there is in fact little distinction between organisms and artifacts.

As we see below, technologies such as the introduction of new genes into developing organisms ("transgenesis"), generation of organisms from preexisting genetic prototypes ("cloning"), and production of organisms of multiple parental or species lineages by mixture of embryonic cells at early developmental stages ("chimerism"), can sometimes give rise to viable plants and animals, and these may have particular scientific, medical, or commercial uses. In each of these cases, however, the techniques employed are different from the intricate and often gradual processes involved in the coevolution and "complexification" of organisms, their subsystems, and the mechanisms by which they develop. The resulting products are therefore artifactual. Just as important, a theory of biological change that could illuminate the relationship of alterations at the cellular or subcellular levels, induced by either natural or artificial means, to changes effected at the level of the whole organism is, as we also see below, available only in rough form. This is despite strong claims that have been made for the triumph of Darwinism and gene-based explanatory models.

Science has been distorted and society in general deceived by corporate executives denying the deadly effects of smoking and pollution, governmental officials denying the causes of global warming, and religious fundamentalists denying evolution. The styles of these abuses differ, however. Corporate leadership and the U.S. government claim to respect the methods and outcomes of science. Dismissal of uncomfortable facts therefore requires the interested parties to suppress evidence, fire whistle-blowers, and fund obliging investigators. The religious perspective is less fearful of and therefore less deferential to science. Whereas scientifically trained religionists wishing to complement mainstream scientific accounts with extraempirical tenets (e.g., advocates of “intelligent design”) may seek to identify implausible or unpersuasive aspects of standard narratives, the more fundamentalist of such thinkers are less reticent about resorting to a supernatural counternarrative that permits them to dismiss scientific findings out of hand.

Biological postmodernists, while sharing the “proscience” modernizing creed of the corporations that typically sponsor their work, also have characteristics in common with religious fundamentalists. Participants in this trend have brought together certain waning biological theories and concepts in the form of an ideology concerning how living systems operate, develop, and have evolved. Like the fundamentalists, therefore, they promulgate a narrative concerning the nature of life that conflicts in significant ways with contemporary scientific thought. Ironically, this reductive, essentially nihilistic set of views is increasingly taken as the hallmark of an informed secularism by libertarians and many liberals.

Biological postmodernism is exemplified in writings on genetically engineered foods by some agricultural scientists and policy analysts.[8] It arises in discussions of human embryo research and prospects of human cloning and genetic modification.[9] Perhaps most surprising is its role in the arguments by which scientists and science advocates have defended the reality of biological evolution against recent creationist assaults. More specifically, biological postmodernism, in adhering to an increasingly questioned exclusively neo-Darwinian paradigm for evolutionary change, represents acceptance of a notion of biological species without boundaries supported by a pseudomaterialistic genetic essentialism.

The particular examples I have chosen and the order in which I present them constitute a progression. Specifically, the postmodernist maneuvers around the first area, GM crops, represent the most transparently commercially influenced and intellectually shallow of these efforts. Those pertaining to the second area, research in human embryology, are a bit more nuanced. While in some cases no less disingenuous on the part of scientists and bioethicists who advance them, postmodern stratagems in developmental biology reflect, as well, unresolved conceptual questions in the field itself. Finally, the postmodernism of creationism’s opponents in the evolution wars represents a poor defense necessitated by an evolutionary theory that, while well established, is underdeveloped in its comprehension of notions of origination and innovation of phenotypic characters.[10] Though the least “interested” and commercially driven of the implementations of biological postmodernism discussed here, those relating to evolution may be most indicative of problems with conceptualizations of the biological world as it exists independently of human activity.

To avoid misunderstanding, I must emphasize that my goal here is not to condemn biotechnology in general nor to privilege some version of nature over culture or civilization, charges that some recent commentators have lodged against virtually anyone with reservations about these techniques.[11] Rather, I propose to demonstrate the extent to which the contemporary discourse around biology has been permeated and distorted by an irrational “religion of technology” and what has been characterized by the philosopher Mary Midgley as the “dreams, dramas, myths or fantasies out of which faiths are constructed to fill the vacuum which is left when more familiar ones are abandoned.”[12]

In order to understand the peculiar synergy of the cultural and scientific notions represented by biological postmodernism, it is helpful to recount briefly the trajectory of recent intellectual history that has led to its easy acceptance by many secular and more than a few liberal religious thinkers.

Biology during the Transition from the Modern to the Postmodern

The revolutions (scientific, political, industrial) that occurred in social organization and scientific thought in European-centered societies beginning four centuries ago shook the foundations of belief systems inherited from earlier periods. The recognition that supposed eternal verities—oppressive rulers with divine claims and one's station in society prominent among them—were products of human action, albeit obscured by overlays of history and ideology, produced in many an optimism concerning human agency and the possibility of changing things for the better.

Scientifically, the new fields of chemistry and physics propounded laws of transformation of matter from one form to another that contradicted older notions of permanence and also put new powers into human hands. Geology and biology in the nineteenth century also discerned laws of transformation—for example, of mountains and species—that while not under full human control, were nonetheless no longer at the whim of a supernatural creator. The industrialization associated with these political and scientific upheavals had its dark, satanic side, but its ravage of ecosystems, creation of new means of warfare and mass killing, and destruction of traditional societies could be considered and portrayed as side effects of overall "progress," at least until the twentieth century.

The modern era, beginning with the Enlightenment (or even earlier, according to some historians), gave rise in the late nineteenth and early twentieth centuries to the self-conscious literary, aesthetic, and philosophical movement known as modernism. Particularly relevant to the postmodernist style of thought that later emerged as both an extension and a rejection of it was modernism's questioning of realistic modes of representation. This tendency, represented by the work of writers and artists such as James Joyce, Virginia Woolf, T. S. Eliot, Pablo Picasso, and Piet Mondrian, has been described as a reaction to the disparities between the ideals and the reality of progress. According to the cultural critic Terry Eagleton:

> All the beliefs that had served nineteenth-century middle-class society so splendidly—liberalism, democracy, individualism, scientific inquiry, historical progress, the sovereignty of reason—were now in crisis. There was a dramatic speed-up in technology, along with widespread political instability. It was becoming hard to believe that there was any innate order in the world. Instead, what order we discovered in the world was one we had put there ourselves.[13]

Science during this period of social uncertainty was undergoing turmoil of its own. The field of modern physics, particularly, had the misfortune of producing two theories—special relativity (1905) and quantum mechanics (1925)—that were theoretically elegant, experimentally sound, but completely at odds with common sense. Additionally, some of its best minds were enlisted to produce the atom bomb, the most powerful destructive device the world had ever seen, which, despite some misgivings and protestations by involved scientists, was used on two population centers, leaving hundreds of thousands dead and many more maimed and sickened.[14]

Biology, in contrast, appeared to be a paragon of conceptual and moral rectitude.[15] The rise of the gene provided a seemingly simple and straightforward explanation for the mysteries of physiology, development, and evolution. Ready and lucid metaphors for gene function were proffered in the form of the blueprint or computer program, the latter, like the discovery of the double-helical structure of DNA, a mid-twentieth-century product. Far from engendering weapons of mass destruction such as nuclear bombs, biology produced the Green Revolution.[16]

The fascist and communist enemies of the Western democracies even embodied particular distortions and rejections of the gene's preeminence—racial purity and Lysenkoism—the suppression of which became part of the good fight against the associated political ideologies.[17]

Still, science and technology, though clearly improving the lives of many in the Western world (but only some in economically weaker venues), was failing to address the deeper disquiet of the modern era.[18] The so-called Cold War, seemingly perpetually on the verge of breaking out into a nuclear holocaust, violent wars of decolonialization in Asia, Africa, and South America, and poverty and social conflict resulting from the legacy of slavery, racism, and constitutional plutocracy in the United States led to a sometimes corrosive questioning by intellectuals of the bases and tenets of the bourgeois social order. Philosophers of the Frankfurt School, such as Walter Benjamin, Theodor Adorno, and Herbert Marcuse, beginning in the 1930s, and allied thinkers such as Simone de Beauvoir and Michel Foucault fostered a turn towards cultural criticism in the academy while influencing the rise of militant international student movements of the sixties and early seventies. The effect of the academic work was to focus the skepticism of the earlier modernist critique of literature and art onto civilization itself, changing the intellectual landscape for both its advocates and opponents in an irreversible fashion.[19] An offshoot of this enterprise was "science studies" or "social studies of science," a field of scholarship that could cast an unsparing light on the production and use of scientific knowledge itself.[20]

Literary and aesthetic modernism and the cultural criticism that grew from it (like the Freudian theory with which they were sometimes allied) were concerned with the necessarily incomplete and provisional nature of knowledge of the self and the external world. The logic of cultural criticism, taken beyond its original purview, also spawned postmodernism, a theoretical stance in which the very notion of objective reality was called into question.[21] According to the postmodernist philosopher of science Bruno Latour, modernism, in its querying of the nature-culture boundary, conceded too much autonomy to each side, the two being inextricably entangled in his view.[22] Postmodernism was lambasted by some on the political right, who, lumping it with feminism and cultural theory, portrayed it as a leftist attack on the notion of scientific authority. But postmodernist positions on the nature of science and social reality also encountered resistance—and ridicule—from scientists and cultural critics on the left who were otherwise receptive to the aims of the earlier cultural critique.[23]

Confined to disagreements on the truth-value of scientific concepts and the extent to which any field of inquiry can legitimately appropriate and manipulate the terms of another, these matters are of mainly academic concern. But as postmodernist thought in the eighties and nineties drifted away from its politically radical roots, it met up with a set of societal changes that would make its epistemological relativism more congenial to the entrepreneurial program than it ever was to any socialist insurgency. In Terry Eagleton's words:

> [W]hat nobody could have predicted was that Western civilization was just on the brink of going non-realist itself. Reality itself had now embraced the non-realist, as capitalist society became increasingly dependent in its everyday operation on myth and fantasy, fictional wealth, exoticism and hyperbole, rhetoric, virtual reality and sheer appearance. . . . The radical modernists had tried to dismantle the distinction between art and life. Now, it seems that life had done it for them. . . . A radical assault on fixed hierarchies of value merged effortlessly with that revolutionary levelling of all values known as the marketplace.[24]

Among the things affected by these changes were the manner in which science was conducted and how natural distinctions and nature itself were conceived, valued, and even ascribed reality. The 1980s saw the simultaneous rise of the aggressively procorporation Reagan administration, which weakened legal restrictions on commerce, of gene analysis and splicing technologies, of patents on living organisms, and of new modes of technology transfer between the publicly funded academic and private commercial sectors. This complex of changes created a need by its potential beneficiaries for a cultural narrative that would justify manipulation and commodification of living systems. During the same period, the increased coherence and visibility in the United States of religion-based opposition to embryo research and the teaching of evolution created the appearance of a reactionary monolith against which the promoters of the new biotechnology could define themselves ideologically as "liberal" and "libertarian."

Postmodernism as a theoretical manifestation of late-capitalist social change and its cultural artifacts—the reconfiguration of family structure, social roles, and gender identities, the melding of "high" and "low" art, Transformer toys and video games, virtual reality and "reality TV"—was ready at hand to provide intellectual cover and a level of comfort (no more "shock of the new") for the new biotechnology. The intersection of market-oriented biomedical research with the now-fashionable ablation of natural distinctions also gave a new lease on life to obsolete early- and mid-twentieth-century notions in the biological sciences. These concepts—genetic reductionism, the fluidity of species boundaries, and evolution as a process of random search with no inherent directionality—had been coming under increased scientific criticism and by the 1980s were in the midst of being replaced by "systems biology"–based ideas.[25] Their lingering, however, proved particularly favorable to a corporate imperative that, echoing the manifesto of the philosopher Francis Bacon in his prescient seventeenth-century utopian fantasy, *The New Atlantis*, sought to employ biotechnology in the "effecting of all things possible."[26]

The postmodernist turn, for example, by devaluing nature and natural distinctions, has supported arguments, more influential in the United States than in Europe, that genetic engineering of crops is no different in principle from either traditional plant breeding or, for that matter, the natural evolutionary process. Coordinately with these efforts, evolution, for its part, has been mischaracterized by biological postmodernists, taking their cue from neo-Darwinian evolutionary theorists, as a product of random search that readily crosses and blurs species boundaries, potentially transforming all biological forms into all others.

Because, as noted above, the material definitions of the embryonic-developmental and evolutionary processes have each been flash points in the assault on both women's reproductive autonomy and the teaching of evolution, there has been a tendency among liberal and libertarian defenders of science in the United States to endorse reflexively all research with embryonic stem cells and to dismiss any suggestion that evolution is anything other than random and opportunistic. More broadly, technophilic bioethicists and other liberal and libertarian commentators have refrained from engaging a traditionalist critique that, despite some scientific shortcomings, reflects a deep (and, some secularists would also argue, healthy) suspicion of the transformation of life, particularly human life, into items subject to selection and material perfection. Finally, postmodernism-influenced opponents of creationism and "intelligent design" have weakened their advocacy of a scientific approach by ignoring the growing acknowledgment within naturalistic evolutionary biology itself of the inadequacy of Darwinian mechanisms alone to account for biological complexity.[27]

Allegations of the pernicious influence of postmodernism have become a familiar refrain from writers defending such purported biological realities as human nature and biological race.[28] This strain of academic antipostmodernism, which takes as its target “political correctness” and other aspects of what it sees as feminism and cultural theory gone awry, has been criticized elsewhere.[29] In the political realm, strangely, postmodernism has been targeted by individuals who show little evidence of having accepted modernity.[30] My critique of the biological postmodernism of corporate-friendly deniers of natural boundaries avoids these contentious arenas by dealing mainly with questions of genetics, embryonic development, and evolution, where scientific consensus on the basic data, if not their interpretation, is often available.

Two additional points need to be made before presenting my main arguments. First, the scientists, commentators, and corporate spokespeople whose views I criticize here have not, in any case that I am aware of, overtly advocated or expressed sympathy with postmodernist thought. Indeed, most would almost certainly be scandalized to find themselves associated with a philosophical movement that is often characterized as an attack on scientific objectivity and even the notion of truth. It is indeed ironic that the rise of biotechnology as a means of production, against the background of an entrenched genetic determinism in developmental biology and evolutionary theory, has brought so many of the “players” in the new life sciences into such close affinity with the postmodernist bête noire. Second, biological postmodernism has been promulgated using ideas about living systems that, however questionable, are still widely accepted and have only recently begun to generate concerted opposition from within science. Although I believe it to be a dubious ideology, I do not thereby mean to suggest that all its exponents in the agricultural and medical fields hold these views in a cynical fashion.

Biological Postmodernism: Three Domains

In the following sections I elaborate on the three examples, mentioned above, of widely followed issues in which either active promotion or tacit acceptance of a postmodern concept of living systems has led to denial of biological facts by scientists and others who present themselves as defenders of science against antiscience New Ageism or religious fundamentalism: (1) attempts by biotechnology companies and some agricultural scientists to undermine public resistance to GM food crops; (2) controversies around human applications of biotechnology involving cloning, stem cells, and chimeras; and (3) the battle over teaching creationism and “intelligent design” in U.S. public schools.

Genetically Modified Crops[31]

Since the first proposals were made to introduce exogenous genes into food and fiber plants, there have been questions raised about the capacity of the methods to create superweeds or adversely affect the health (i.e., by toxicity or allergenicity) of those who consume them.[32] By 2005, however, when more than 90 percent of the annual soybean crop and 50 percent of the corn crop in the United States had come to be genetically engineered—a transformation in agricultural production that took less than a decade—efforts at regulation that had made sense in a precautionary framework could now be portrayed as irrational.[33] Indeed, as some advocates would have it, resistance to GM food now implies that one wishes to avoid eating, to undermine the U.S. economy, and, for leaders of countries with undernourished populations, to deprive their citizens of food aid.[34]

Up to now, virtually all genetic modification of food and fiber crops has been directed towards enhancing the economic aspects of crop production (i.e., resistance to herbicides and insect damage, increasing shelf life) rather than improving nutrition or flavor.[35] There have thus been enormous financial incentives associated with introducing genetic engineering methods into agriculture with little concomitant benefit to the consumer other than, in certain cases, pricing. But the grip that agribusiness corporate directors have come to exert on food and other crop production since GM products were first introduced in 1996, in the form of patents that prohibit replanting of saved seed as well as pressures on farmers via their insurance companies not to seek alternatives, suggests that any efficiencies in production arising from genetic engineering will in the long term not even be reflected in lower prices.

With the hazards of GM crops not allayed and the benefits to the general public not compelling, the means by which several important traditionally bred food crops came to be replaced by GM counterparts in the United States with little opposition, compared with Western Europe, is of great interest.[36] While the institutional and anthropological aspects of conflicts around GM foods have been written about incisively, additional insight can be gained by considering the role in this process of biological postmodernism.[37]

The relationship between an organism's genotype—the full complement of its genes—and its phenotype—its form and array of functional attributes over the range of environments in which it is viable—is one of the great unsolved problems in biology. It is studied by developmental biologists, physiologists, ecologists, and behaviorists, among other scientists, and there is little consensus across or even within these fields as to what the rules and regularities of the genotype-phenotype relation are. The simplistic notion of "one gene, one trait" suggested by some classic Mendelian studies was rejected as a general principle early on by plant and animal geneticists.[38] But equally misleading concepts such as the "genetic program" or the "genetic blueprint," collectively referred to as genetic reductionism or determinism, held on despite their inability to provide explanatory links between genotypes and anything but the most basic molecular aspects of phenotypes.[39]

In conventional agronomy, breeders select phenotypic variants associated with spontaneous mutations of genes that have coevolved with all the other genes of the particular plant over tens or hundreds of millions of years. Methods of chemical- or radiation-induced DNA mutagenesis used earlier in the twentieth century, prior to the GM era, can change the sequence, or rearrange the position in the chromosomes, of the coevolved genes. These "classic" mutagenesis methods and some newer genetic engineering techniques that simply inactivate existing genes, while they may have unpredictable effects on the organism's morphological phenotype (shape, form, arrangement of parts; see the following sections), do not add molecular functionalities uncharacteristic of the species. In contrast, "transgenesis," the most commonly used GM technique, involves introducing genes from distant species into a plant or animal's genome—bacterially derived herbicide or pest-resistance factors in soybeans and corn or fish-derived antifreeze proteins in tomatoes, for example. But throwing an entirely new component into a plant's biological mix can potentially change the levels of the hundreds to thousands of potentially toxic molecules every plant is capable of manufacturing. Moreover, different transgenic insertions of the same gene into the same plant can result in vastly different phenotypes due to variations in the position of insertion in the chromosomes. In addition, GM transgenesis can inadvertently induce extensive scrambling of the genome.[40]

It is significant in this regard that "lateral gene transfer"—that is, natural transgenesis—into plants or animals from evolutionary distant sources such as bacteria has been extremely rare in the history of life.[41] In cases where it has been documented to have occurred, it has had major consequences to the plant's phenotype.[42]

Scientific advocates of GM crops take comfort in the observation that "phenotypes and metabolic pathways tend to be buffered from the effects of mutations."[43] However, such buffering mechanisms, whereby a plant or animal can develop into a form characteristic of its species despite alteration or even complete inactivation of many genes, are products of integration of the genome through coevolution of genes and natural selection for developmental stability.[44] They would only fortuitously and inexactly pertain to transgenic organisms. The assertion that the outcomes of transgenesis are more predictable than traditional breeding or mutagenesis because the manipulations are more precise at the DNA level simply ignores the findings of cell physiology and evolutionary biology.[45]

Introduction of products based on novel technologies have traditionally been advertised as "new and improved" or even "revolutionary"; in particular, their differences from existing counterparts have been emphasized and portrayed as beneficial. With regard to GM food, it became clear early on that this strategy of differentiation would not work; people were too suspicious of significant changes in what they eat for them to respond positively to such claims. It became necessary instead to reassure the public that nothing in the nature of their food crops would change despite the new methods (sold to potential investors, paradoxically, as unprecedented in their power) used to produce them. By conflating GM transgenesis with conventional mutagenesis, traditional selective breeding, and evolution itself and portraying it as nothing new, several stratagems of biological postmodernism were brought to bear on selling GM foods to the public and, more important, to corporate and governmental leaders. In the United States these were mainly directed to undermining distinctions between the natural and artifactual. Insofar as such maneuvers were successful, agribusiness was aided by academic and think-tank intellectuals and regulatory agencies, which, regardless of the political party in power, seemed only too eager to go along with them.

Genetically Modified Crops as Substantially Equivalent to Traditionally Bred Crops

Before GM crops were placed on the market in the United States and Europe, a series of reports were published by national and international deliberative bodies that had considered potential hazards of GM crops. Among the earliest and most influential of these reports was the document *Field Testing Genetically Modified Organisms: Framework for Decisions*, published in 1989 by the National Research Council (NRC), an arm of the U.S. National Academy of Sciences. Despite earlier discussions at the National Academy itself and throughout the international scientific community that acknowledged some of the complexities and pitfalls of transgenic manipulations mentioned above, the NRC report stated quite simply that "no conceptual distinctions exist between genetic modification of plants and microorganisms by classical methods or by molecular techniques that modify DNA and transfer genes."[46] Since "classical" methods included spontaneous mutagenesis, that is, the source of the genetic variation in coevolved genes in cultivated populations of plants, the assertion was a stretch. The further statement that "the same physical and biological laws govern the response of organisms modified by modern molecular and cellular methods and those produced by classical methods" finally spun the report into the realm of the postmodern; as noted above, the "biological laws" governing the genotype-phenotype relationship (the only biological laws relevant in this case) are all but unknown with regard to organisms with changes in existing coevolved sets of genes and are nonexistent for organisms containing genes imported from other species.

The main conclusion of the NRC's report was that "the *product* of genetic modification and selection constitutes the primary basis for decisions on the environmental introduction of a plant or microorganism and not the *process* by which the product was obtained."[47] Four years later, when the international Organization for Economic Cooperation and Development (OECD) met to produce the report *Safety Evaluation of Foods Derived by Modern Biotechnology*, the U.S. position, based on the NRC's dismissal of any special issues arising from genetic modification of crops, held sway, crystallizing into the OECD's doctrine of "substantial equivalence" of GM and traditionally bred plants.[48] While initially serving as a basis for international consensus on the global marketing of GM foods, the "substantial equivalence" doctrine came under increasing attack in the United Kingdom and other European Union countries over the next decade as new data from field and laboratory tests exposed it as unscientific and ill defined. In the United States, however, it remained the operative principle governing the regulation of transgenic GM crops.[49] But at this late date there are still no adequate testing methods in place to screen for phenotypes harmful to the environment or human and animal health potentially generated by transgenic GM techniques.[50] While this is also true for conventionally bred crops, as noted above, the phenotypic novelties that may arise from transgenesis are likely to be different from those latent in the population or inducible by alteration of existing coevolved genes.

Genetically Modified Foods as Organic Foods

The U.S. Congress, in a farm bill enacted in 1990, directed the U.S. Department of Agriculture (USDA) to establish criteria for certification of foods as "organic." Though not a scientific term, "organic" on a label was meant to assure people that food crops have been produced by a management system that "promotes and enhances biodiversity, biological cycles and soil biological activity . . . based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony."[51] Imprecise as this may be, it is fairly obvious what kinds of processes and products consumers of organic food favor: as distant as feasible from the high-tech, chemical-intensive monoculture characteristic of the large-scale, absentee-owned, contract-farmed, agricultural enterprises.

Apart from questions of whether organic farming embodies all the health and environmental advantages claimed by its supporters, there is the issue of people's right to know what they are eating. The debate over the definition of organic food is thus an example of what the science and technology analyst Sheila Jasanoff refers to as "boundary work" by which the demarcation between the natural and the unnatural is negotiated in any society.[52] With the doctrine of substantial equivalence in hand, corporate leaders in the agricultural biotechnology sector and their academic allies took up the cause of negotiating the natural/unnatural boundary and had the Clinton administration's Secretary of Agriculture Dan Glickman issue proposed USDA standards making GM food (as well as food irradiated to increase shelf life or grown with the aid of toxic sewage sludge) eligible for labeling as organic. A massive public protest in the form of several hundred thousand letters prevented the USDA from implementing this proposal in 2000.

Traditionally Bred Foods as Genetically Modified Foods

With substantial equivalence in disrepute everywhere but in the United States and the U.S. campaign to get GM foods labeled as organic a failure, deregulating the technology entirely, so as to end all public awareness and scrutiny of it, moved to the top of the industry's agenda.[53] The final arrow in the biological postmodernists' quiver was therefore released: the denial of any distinctiveness whatsoever to genetic engineering technology.

In 2003 a commentary on new research on the origins of maize was published in the journal *Science*.[54] The article itself was an unexceptionable summary of what is known about the cultivation of maize over the past four thousand years, placed in the context of retrospective knowledge of the genes involved. Only the last sentence, which concluded that "the rapid adoption of superior GM crops today . . . is far from a new phenomenon," referred to present-day technology, but the piece in effect denied that GM foods represent novel agricultural products by the maneuver of defining all cultivated crops, extending back to the New Stone Age, as genetically engineered. The author, an academic scientist and a member of the board of directors of Sigma-Aldrich, a company that markets pharmaceutical products extracted from transgenic corn, was not explicit about her intention of shifting the discourse concerning genetic engineering of crops by obfuscating its differences from traditional breeding practices until confronted by other scientists in *Science*'s letters column. And indeed, the magazine's editors colluded in helping her slip this "reframing" of the field past readers and into the scientific literature when they permitted her to give the article its provocative title, "Agriculture: Prehistoric GM Corn," and allowed her to leave her corporate affiliation off the author's note.

Some of the comments received by *Science* in response to the article are instructive. One correspondent stated, "N.V. Fedoroff's Perspective 'Prehistoric GM corn' . . . seems calculated to obscure important issues in the debate over the safety of genetically modified organisms (GMOs)," while another asserted, "It is not a question of whether genetic engineering is good, bad, or irrelevant, but clarity of understanding requires that a distinction be recognized." In her reply Fedoroff stated, "[I]t is time to eliminate the altogether artificial boundary between what humans did before molecular techniques were developed and what they do now to improve their crop plants," and then went on to conflate spontaneous mutations, radiation-induced mutations, and transgenesis.[55] As noted above, the last of these, the characteristic method for producing GM crops, is entirely different from the first two.

Human Developmental Biology

The controversy around abortion, though heated and divisive, is an old one. The dispute has focused on whether a developing human before a given age or stage of development has a "right to life" or is indeed due any individual regard, but there has never been any question on either side of the issue that what is eliminated by an abortion is an embryo or fetus. Starting in 1978, however, with the first human birth (in the United Kingdom) resulting from in vitro fertilization (IVF), the embryo became objectified in a new way. Even though the original goal of IVF was reproduction, the embryo's independence from a woman's body made it easier to discard if it failed to meet certain standards or to improve, to buy and sell, and to transform into something with other uses. In just a few years after the first IVF birth, the British Committee of Inquiry into Human Fertilisation and Embryology published the Warnock Report on human fertilization, which proposed that the developing human prior to day 14 of development be redefined as a “pre-embryo.”[56] This designation, which is not used in the scientific or popular literature for the developmental stages of any other organism (a fertilized frog egg, for example, is called simply an embryo), established a biological entity that while no longer a human embryo (which some people found inappropriate as an experimental system), could nonetheless be studied to gain knowledge of human development.

It should be recognized that objections to modifying or otherwise experimenting on human embryos is not the same thing as seeking to limit women’s reproductive autonomy by curtailing the right to obtain an abortion. Opponents of human embryo research argue that adapting the methods by which mouse embryos have been cloned and genetically modified to human embryos (even if only to produce stem cells) will clearly enable the production of full-term cloned and GM humans. There are no laws in the United States or most other countries to prevent this, nor is there currently a consensus to move in that direction. For every scientist working in this field who disavows the goal of generating full-term cloned humans, there are several bioethicists providing arguments against such misgivings.[57] But one can simultaneously hold a pro–reproductive choice position and still have concerns about the ways in which scientific advances in experimental embryo manipulations enable the production of altered humans. Put another way, accepting that a woman has a right to terminate her pregnancy does not thereby create a right for others to do what they wish with the embryo or fetus.

Defining an unmanipulated human embryo as something other than an embryo in order to circumvent taboos on its objectification clearly resembles the postmodernist maneuvers discussed above in relation to GM food crops. It is significant, however, that on the conceptual level it has exactly the opposite goal: to enforce rather than erase distinctions between the artifactual and the natural. Of course, such reversals present no problem for biological postmodernists, for whom such distinctions are arbitrary and subject to redefinition as required. Thus, in the case of GM crops, since no one seeks to restrict scientists’ experimentation on plants but only the release into the environment, marketing, or public ignorance of the products of this research, it is in the interest of agribusiness owners to obscure the difference between GM and traditional crops. In contrast, since there are objections, for various reasons, to experimentation on human embryos, it is in the interest of those who wish to do so to reinforce any distinction between embryos destined to develop into persons and those used in the laboratory. Louis Guenin, for example, calls any in vitro–produced human embryo donated to medicine (even beyond the fourteen-day “pre-embryo” cutoff stipulated by the Warnock Report) an “epidosembryo”—an embryo for the common good—for which a moral imperative pertains to its utilization.[58]

Under these circumstances and in view of the evolving technology, two important questions present themselves: (1) At what point do manipulations such as cloning and genetic manipulation actually transform an embryo into an artifact, fortifying, if only after the fact, arguments for excluding it from moral consideration for purposes of experimentation or organ harvesting? (2) As increased success with manipulations leads toward the production of full-term clones and GM humans, by what rationalizations will entities whose artifactual nature was asserted in the course of process (1) come to be selectively portrayed as “substantially equivalent” to humans?[59]

The various ways in which human biological entities have been reframed and redefined to accommodate new reproductive technologies and research strategies can be appreciated in the examples that follow.

Clones as Persons and/or Artifacts

The report in 1997 of the cloning of a mammal, Dolly the sheep, elicited a burst of enthusiasm from technophilic business executives and politicians hoping to see full-term human clones in their lifetime.[60] Some religious thinkers were quick to give their endorsement to this enterprise. According to Ted Peters, a fellow at the Center for Theology and the Natural Sciences and a professor at Pacific Lutheran Seminary, "Surely, [a cloned human] would be just as much a child of God and loved by God. They would have their individuality, they would have their dignity, and certainly they would have their own souls."[61]

The "certainly" is a little troublesome. No commentators in this vein, secular or religious, addressed the patently artificial character of the cloning process, which involves combining nonviable fragments of two seriously damaged cells, an egg that has had its nucleus extracted and the isolated nucleus of a somatic (differentiated tissue) cell. (Even IVF, opposed by some on the basis of unnaturalness, still employs the material entities that have evolved as part of the human species to produce a human being—an egg and a sperm.) One may ask what ensures the humanity of the resulting assemblage. The ensuing organism may look human (or in Dolly's case, like a sheep), but so, presumably, would one constructed of chemically synthesized egg-cytoplasmic components and nuclei containing synthetic human DNA. Would such manufactured organisms also have souls (assuming these exist) just by virtue of the fact that they looked like people? The DNA of humans and the DNA of chimpanzees have extensive identity along most of their sequences;[62] the synthetic DNA in our hypothetical example could easily be made intermediate between the two species.

For religious believers for whom the notion of a living soul (particularly a human soul) is a regulative concept, the very prospect of creating such mixtures would seem to provide motivation for supporting barriers to certain forms of biological manipulation. As we have seen, however, genetic essentialism and the technological imperative are often sufficient to overcome any qualms along these lines.

The question of how much human DNA is needed to qualify an organism for a soul was not at issue for the biologists Richard Lewontin and the late Stephen Jay Gould, both of whom are known for their opposition to overemphasizing genes as determinants of key human characteristics. Yet when the cloning of a mammal was first announced, each stated that a full-term cloned human would not represent anything unprecedented biologically, since identical twins, a normal part of human communities, are also individuals having the same DNA.[63] Apart from the social novelty of producing people asexually from existing prototypes (which one would imagine to be a compelling distinction for these Marxist-oriented scientists), the conflation of clones with twins seems oddly nonmaterialistic. For one thing, the DNA of differentiated cells is chemically altered compared to that of the fertilized egg.[64] And while the reversal of these alterations when a clonal embryo starts its (usually unsuccessful) developmental trajectory occurs by mobilization of available biochemical processes, these processes, not having been under evolutionary selection to perform this particular function, can only do it in a fortuitous and approximate fashion.

Significantly, both religious commentators such as Peters and secular ones such as Lewontin and Gould seek to erase the differences between clones and "naturals" by taking DNA sequence alone, rather than the species-specific developmental process, as the defining characteristic of the human. It is ironic that genetic essentialism provides their common meeting ground.

Blurring the distinction between humans constructed from portions of damaged cells and humans produced by fertilization will ease the way for acceptance of this form of "reproductive choice" once certain technological glitches are overcome.[65] Scientists who wish to pursue this work in the short term, however, must contend with the significant portion of the public that objects to experimentation on human embryos and whose representatives control the purse strings for research funding. Some of these scientists—such as Rudolf Jaenisch of the Massachusetts Institute of Technology, whose own work in this area has led him to state, "Out of all the animals ever cloned, I'm not sure whether any normal clone has yet been produced"—have emphasized the aberrant nature of clonal embryos and their permanent unsuitability, in the human case, for being brought to full term.[66] Jaenisch has gone so far as to suggest that since "[a] cloned embryo has an exceedingly low potential to ever develop into a normal baby because of the overwhelming problems associated with reproductive cloning. . . . [w]hether the cells that result from this process are a new embryo or simply rejuvenated skin cells is as much a question of philosophy as of science."[67]

Things were now ripe for the biological postmodernists to rush in. In December of 2002 Stanford University announced the establishment of a new Institute for Cancer/Stem Cell Biology and Medicine under the direction of Dr. Irving Weissman. Some of the institute's proposed work with human embryonic stem cells (ES cells) would involve producing customized early-stage embryos in which a cell nucleus from an individual with a genetic condition under investigation (or perhaps later a patient who is a candidate for grafting of ES cell–derived tissues) would be transferred to an egg whose own nucleus had been removed. That is, clonal embryos would be produced—though Stanford was at pains to emphasize that this was not the case. Stanford's official spokesperson was quoted in news reports at the time as stating, "We're not cloning embryos, and we're not going to clone embryos." Of course they were planning to clone embryos, just not bring them to full term. This could have been made clear in a scientifically accurate fashion. Instead, Weissman himself asserted that his planned research was "not even close" to cloning.[68]

At around the same time, the International Society for Stem Cell Research (ISSCR) was established, a self-described "independent, nonprofit organization formed . . . to foster the exchange of information on stem cell research.".[69] This organization, in which Irving Weissman serves as an officer, began working to ensure that what developed from an enucleated egg into which a somatic cell nucleus had been inserted was no longer referred to as an "embryo." This term was to be reserved (according to the society's online glossary) exclusively for the product of fertilization of an egg by a sperm. Thus the ISSCR put itself in the position of holding that the entity that gave rise to Dolly the sheep (a "somatic cell nuclear transfer [SCNT] product," in the society's terminology) was not an embryo. The logical conclusion is that Dolly herself was not an actual sheep and that any individuals that might in the future be generated from human SCNT products would not be exactly human.

Contrary to the religious philosophers who asserted that full-term clones would be endowed with souls by a loving God and the Marxists who claimed they were ordinary people no different from twins, one of the major liberal groups that arose in support of ES cell research, the Genetics Policy Institute, characterized efforts to produce full-term clones as a "crime against humanity."[70] Its objections, however, which relate primarily to the safety of the procedure, could potentially be allayed by successes with animal cloning.

The choice of terminology in regard to cloning technology, like that concerning GM crops, has large financial implications. During a 2004 ballot initiative campaign to direct the state of California to provide more than $3 billion in funding for stem cell research, a group of individuals including Stanford Nobel laureate Paul Berg unsuccessfully sued a coalition of the initiative's opponents to prevent them from referring to SCNT products as "cloned embryos." One of their arguments was that since the prospective recipients of the funds had no intention of implanting the SCNT products in a woman's uterus, the products were thereby not embryos. The attribution of inherent material properties to an object by virtue of the intentions of its possessor is, strictly speaking, magical thinking. However, biological postmodernism provides an equally apt way of conceptualizing this maneuver.

Chimeras as . . . What?

As seen above, despite the manipulations necessary to produce genetically engineered crops and clonal embryos, the resulting organisms retain enough of the identity of their originating species to leave at least a rhetorical opening to anyone who would define them as natural. In fact, the extraordinary resistance of species character to being altered by genetic manipulation (see next section) conflicts with the expectations of neo-Darwinism, the standard model of evolutionary change (see next section). It represents a constraint on what biotechnology can accomplish, but it is a surmountable constraint if the technologist is inclined to take things further.

Chimeras are animals in which species identity may be blurred beyond recognition. The term can be used for any organism that contains grafted tissues originating in another species. But whereas an organism that has undergone its full course of development will not be changed in any essential fashion by such grafts, if performed during embryogenesis the effect can be more profound. An extreme version of animal chimerism can be brought about by mixing cells from early developmental stages of different species of animal to create a composite embryo. If brought to full term, the resulting body contains organs and tissues that are a mosaic of cells of the originating species. This is the technique that was first used successfully in the 1980s to produce "geeps," animals that had an appearance and biological character part way between goats and sheep.[71]

Unlike hybrid animals such as the mule (the outcome of the mating of a donkey and a horse), chimeras produced by embryo-cell mixing are not infertile but they also do not reproduce their own kind. Female geeps produce both goat and sheep eggs; males geeps produce a mixture of goat and sheep sperm. The mating of two geeps may produce a goat, a sheep, or a goat-sheep hybrid (which is not viable) but not another geep. Embryo chimeras are therefore true biological artifacts—organisms of indeterminate species identity whose progeny are nonetheless typical members of recognizable species.

Though unquestionably artifactual, embryo chimeras did not mobilize postmodernist reframing exercises until humans were put into the mix. In 1998, the report that a U.S. patent had been applied for on "chimeric embryos and animals containing human cells" elicited the unusual public pronouncement from an official of the U.S. Patent and Trademark Office that nothing so offensive to public morality would be permitted to be patented.[72] The patent application was a preemptive ploy to bring the technical possibility of making human-animal chimeras to the public's attention, and at the time it was announced, some scientists portrayed it as a slander on their profession.[73] Philip Leder, the biologist who, a decade earlier, had obtained the first patent on a transgenic animal, the OncoMouse, stated on the National Public Radio program *All Things Considered*, "The creation of chimeras is an outlandish undertaking. No one is trying to do it at present, certainly not involving human beings."[74] But a few years later a group of Rockefeller University scientists announced that they intended to produce human-mouse embryo chimeras as an aid to studying the potential of human embryonic stem cells to develop into various tissue types, and in June 2006 they reported their success in constructing embryo chimeras containing human and mouse cells.[75]

Production of chimeras in which human neural stem cells are introduced into the brains of embryonic monkeys or mice are also under way. One of the investigators performing these studies is Irving Weissman of Stanford University, mentioned above. Weissman has stated that he would like to construct a mouse that has a brain composed entirely of human cells. When questioned in a Public Broadcasting Service report whether "scientists like yourself working in this field [are] treading through a legal and ethical minefield when you do this kind of research," Weissman replied, "Absolutely. It's a good thing we're treading on ethical grounds. It means we're getting close to important issues."[76] The implication of this seems to be that the transgressiveness of the proposed manipulations is desirable in itself, a doctrine best known as a tenet of postmodernist art.

The malleability of species identity and its limits are perennial elements in discussions of the future of the human species.[77] Emergence of human subspecies that may eventually have little to do with or have an antagonistic relation to one another is anticipated by both advocates and critics of human applications of gene manipulation analogous to those used in GM crops.[78] Whether or not a breach of species boundaries or change in species nature can be accomplished by these methods, it is unquestionable that they can be achieved by chimerism.

Chimerism therefore provides a reference point *in extremis* for evaluating the report on human-nonhuman neural grafting described at the beginning of this paper, a report that "unanimously rejected ethical objections grounded on unnaturalness or crossing species boundaries."[79] What lies down this increasingly mainstream biological postmodernist road can be judged from a catalogue essay by Christoph Cox for the 2005 art exhibit "Becoming Animal" at the Massachusetts Museum of Contemporary Art. Cox discusses the writings of the philosophers Gilles Deleuze and Félix Guattari for whom, he claims:

> there are no essential differences within nature, no absolute differences between minerals, vegetables, animals, and humans. Rather, matter is a vast continuum, a field of virtual forces, intensities, thresholds and powers that, under particular conditions, is actualized in the things and bodies we know. But these things and bodies are not fixed, stable, or given once and for all. They themselves are bundles of forces and capabilities that are constantly undergoing changes prompted by encounters with other entities into which they enter into relationships.[80]

Neo-Darwinian evolutionary theory makes the strong assertion that even in the natural course of things, species have vague boundaries and are always on their way to becoming something else (see next section).[81] However, an increasing number of evolutionary biologists and philosophers of biology have suggested instead that species are "natural kinds." This is not because they have preordained essences but because they exhibit causal homeostatic mechanisms that enforce their type-specificity.[82] If species barriers are real, then, not ephemeral or chimerical, it becomes reasonable to consider their preservation, like the preservation of wilderness areas, wetlands, languages, and species themselves, as a positive value. I return to this in the concluding section. In the penultimate one I describe how biological postmodernism relates to current ferment in evolutionary theory and how this is playing out in the conflicts in the United States around the teaching of evolution.

The Evolution Wars[83]

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 of the developed 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 antievolutionary counternarratives. Nonetheless, there exist several schools of thought that represent themselves as scientific and seek to capitalize on inadequacies or flaws in various versions of the account of mainstream biology.[84] While “Young Earth creationism” adheres closely to biblical accounts of the genesis of the world and its creatures, holding that life was established on Earth around six thousand years ago, the more recently established “intelligent design” movement generally accepts the age of the Earth as determined by science and even allows a role for evolution in molding many biological features (the overall structure of the bodies and appendages of insects, humans, and other many-celled organisms, for example) but asserts that other features, such the flagella, the microscopic beating whips on the surface of cells, are “irreducibly complex” and can only have been generated by a “designer” located outside the frame of naturalistic thought.[85]

The mainstream secular characterization of this debate is that it represents a clear choice between rationalism and irrationalism. However, few contemporary religionists, even the most fundamentalist, question mechanistic and other naturalistic accounts of observable phenomena. This is clearly a departure from traditional cultures in which animistic explanations of things like fire and the weather were standard. Nor do most religious believers in the developed world reject out of hand medicines and surgical procedures based on the conception of the living human organism as a material object that obeys the laws of physics and chemistry. And whatever they may think about how a cell’s flagella originated, the idea that its motion occurs by standard physicochemical processes is uncontroversial to the large majority of religionists.

Why, then, do so many people reject an evolutionary account of the origination of complex biological systems? First, it must be recognized that in contemplating the origins of the world as we know it, most members of advanced technological societies, including a fair number of scientists, are comfortable bringing supernatural causation into the picture at some point, usually in the distant past.[86] 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, experienced life is more important than what occurred three billion or even six thousand years ago. People’s experience of organismal types—wild and domestic animals and plants—focuses and indeed depends on the constancy of the species’ identities, not the possibility that they are on their way to changing into something else.[87] Excluding perhaps 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 biological postmodernist jibes, such as the 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.[88]

Such ultimate questions are, of course, irrelevant to the criteria that most people use in judging whether their lives are meaningful. Moreover, Darwinism itself, which concerns populations of organisms, not molecules, has nothing to do with these issues except in an ideological sense (see below). The failure to persuade of such thumbs-in-the-eye as Monbiot's or similar ones by the arch-Darwinist Richard Dawkins[89] is therefore not surprising, and this is not just a matter of the obduracy of fundamentalists.

In making the case for a scientific alternative to traditional accounts of natural phenomena 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 good theory.[90] Does Darwin's theory of evolution by natural selection meet this standard?

The Problem of Evolutionary Innovation

Incremental changes in an existing 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.[91] Even most creationists do not deny this. But when it comes to the *innovation* of entirely new structures ("morphological novelties") such as bodies or body axes organized as segments (seen in earthworms, insects, and vertebrates such as humans but not in jellyfish or octopuses), or the uniquely structured hands and feet of tetrapods (four-limbed animals, a subset of vertebrates), 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."[92]

Contrary to the expectations of the standard Darwinian model, the fossil record is deficient in transitional forms between major innovations.[93] And although our current knowledge of the cellular and genetic mechanisms of the development of animal forms is relatively sophisticated, there are few plausible scenarios involving gradual 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, with the only criterion for evolutionary persistence being "whatever works."

The belief that a scientific-materialist worldview implies this second possibility was termed "Darwinian fundamentalism" by the late Stephen Jay Gould.[94] Biological postmodernism draws sustenance from Darwinian fundamentalism because of its allied supposition that living systems are arbitrary assemblages of gene-determined traits, with no preferred (i.e., "natural") forms or routes of change.

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 recognition 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 protein and RNA products 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 molecular 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.[95] Since whether or not **[[Please retain 'or not' here]]**a given molecular-genetic network behaves as an oscillator depends on small variations in the constituent genes and their products, segmentation, as a morphological novelty, can have emerged multiple times, in a relatively sudden fashion, from unsegmented ancestors of modern segmented animals.[96]

Segmentation is just one case 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.[97] In general, if living tissues are physical materials, their forms and behaviors must be subject to forces and determinants apart from their genes; indeed, they must exhibit condition-dependent variability, a phenomenon that has been termed "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.[98] 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 is thought to be the result of this progressive evolutionary reinforcement of developmental trajectories, termed "canalization."[99] In addition, if the "self-organization" of living tissues (of which the molecular clock phenomenon mentioned above is just one example) was efficacious in originating and innovating forms during early evolution, 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.[100]

The real possibility that the evolutionary origination and complexification of organismal features has been the result of a plasticity-based "phenotype first, genetic programs later" scenario, rather than the gradualist, gene-driven processes of neo-Darwinism, makes the whole enterprise of improving phenotypes of plants and animals by genetic tinkering (see previous sections) scientifically naive. Natural selection has indeed led to the phenotypes of modern-day organisms being resistant to perturbation. But as complexity theory has shown us, while evolved systems are typically highly robust to perturbations encountered (and fortified against) during the evolutionary process by which they were generated, they are often exquisitely vulnerable to unforeseen disturbances.[101]

Hegemony of the Darwinian-Mendelian Synthesis

Phenotypic plasticity, a relatively common property of developing organisms that was appreciated by many nineteenth-century biologists and 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 in evolutionary theory during the twentieth century.[102] 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, the main conceptual effect of Darwin's theory of evolution by natural selection was to marginalize the concept of organismal plasticity and, once the theory's scientific hegemony was established, to consign all the real phenomena that fit this description to a theoretical limbo. Furthermore, by making the claim (in the first chapter of *The Origin of Species*) that the small effects that can be brought about by domestication are of precisely the same kind as those that have driven large-scale ("macro") evolution, that is, that the natural (natural selection) could be understood by means of the artificial (artificial selection), Darwin himself laid the foundation for the elision of the natural and artifactual that we have seen pervading modern, technology-oriented biology.[103]

The other major scientific reason for the marginalization of the concept of organismal plasticity was the successes in applying the Mendelian paradigm early in the twentieth century. The nineteenth-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 twentieth 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 by most biologists 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.[104]

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 other 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 to be one of the most powerful ideas ever produced by science.[105]

Other strains of early-twentieth-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.[106] During the emergence of gene-centered biology in the 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-twentieth-century biology in the United States and Western Europe. The adoption by the Soviet Union of the anti-Mendelian policy of Lysenkoism in agriculture and then in research biology and the purging of geneticists from the scientific institutes presented the capitalist powers with a vivid example of the corruption of science by a command economy.[107] 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 postrevolutionary philosophy of science. And although the failures of Lysenkoist agricultural policy were hardly worse than those of the Mendelism-based agricultural policies earlier on, Soviet biology was severely damaged by Lysenkoism.[108]

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 derision 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 beginning to emerge during the last decades of the twentieth 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, biochemical oscillation), the entire enterprise has nonetheless been portrayed, inaccurately, as the triumph of the Mendelian paradigm.[109]

Evolutionary Postmodernism

Lysenkoism represented an ideological distortion of evolutionary biology that may be thought of as characteristic of 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 provoked, in its parceling of life into separable, swappable, and most importantly, patentable modules, comports well with the worldview of advanced capitalism.

Working in the classic naturalist mode of Darwin himself, who was concerned with the inheritance of traits rather than genes, a number of scientific and popular writers have presented elegant and persuasive (to those inclined to be persuaded) accounts of the role of natural selection in the molding of particular characteristics and propensities in the plant and animal worlds.[110] As with Darwin's original theory, they make no attempt to deal with the aspects of life that need to be explained in order to recruit to an evolutionary narrative people who would just as soon hold onto their religious beliefs concerning where life came from, why it is organized the way it is, and how novel forms originate.

Biological postmodernism, however, drawing on a late-twentieth- to early-twenty-first-century gene-centered evolutionary ideology (what the philosopher Mary Midgley has called "evolution as a religion" and the historian and philosopher of science Michael Ruse, "evolutionism"), purports to answer all these questions.[111] But it does so with a wave of the hand: a theory (neo-Darwinism) in which the forces generating biological variation and the natural constraints on those variations are barely relevant. According to a prominent neo-Darwinian theorist, "our understanding of the molecular basis of development—however fascinating and important in revealing the hidden history of what has happened in evolution—sheds little light on what variation is potentially available for the use of selection."[112] The neo-Darwinian literature evinces little bad conscience about this state of affairs.

With their genetic-determinist blinders on, standard evolutionary accounts do not draw on the novelty-generating phenomena of large-scale phenotypic conversion of a population by external factors (seen even in present-day organisms like plants and social microbes) and evolutionary change occurring in preferred directions due to the material properties of developmental systems.[113] 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 phenotypic changes (because what else is there?). Which 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.

Genetic-determinist ideology, moreover, has had cultural ramifications that extend well beyond its belatedly loosening grip on scientific research. 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 that, once genetic engineering became feasible in the 1980s, 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.[114]

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.[115]

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 type of 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 nanoscale molecular machines within the cell present genuine challenges to neo-Darwinian incrementalist scenarios. Even Francis Crick, the codiscoverer of the structure of DNA, was not convinced that conditions on the prebiotic Earth were compatible with the chemical evolution of the genetic material.[116] In the quarter century since Crick first expressed these doubts, 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.

But rather than intelligent design's facile positing of a nanoengineer God, what is called for are new scientific principles of self-organization on the small scale. There are earlier precedents for new theories emerging to organize and explain anomalous findings. The structure of individual atoms, for example, as manifested in their interactions with light upon being heated, was completely enigmatic until Erwin Schrödinger and Werner Heisenberg independently developed the unprecedented and counterintuitive laws of quantum mechanics in 1925. The best physicists of the early twentieth century acknowledged that the old ideas were not adequate to these phenomena. 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.

As with the pressure to foist genetically engineered foods on the public and the drive to overcome reservations about the production of modified human embryos and quasi-humans, the advocacy of the standard concept of evolution is too often characterized by a disdainful attitudinizing toward received beliefs and value systems that, give or take where to draw exact lines of demarcation, are actually shared by most people on both sides of these issues. All three efforts are bound together by biological postmodernism, an antitheory of biological change that attributes agency to genes rather than to the complex systems that contain them and, making little or no attempt to provide accounts of why organisms have the properties they do, denies the existence of "the natural" as a regulative category. The scientific mainstream, which should rightly be prevailing in the evolution debate (since the living world is manifestly a product of evolution), is so committed to neo-Darwinism's "context of no context" that they are barely holding on in their attempts to prevent supernatural accounts of the history of life from being placed on par with naturalistic ones in the educational system.[117]

Conclusion

We are misled about the character of the world we live in if we believe that the changes we can induce in organisms with our recently invented biological technologies are the same as the formative processes that brought about organisms in the first place or caused them to diversify over the long course of evolution. We are similarly deceived if we imagine that knowledge of the genetic constitution of organisms is all that is needed to make and remake them without doing harm. As we see above, however, these false notions of life, its nature, and its history are definitely in the air, and they have increasingly been dominating the discourse on agricultural and biomedical policy in the United States. A recent commentary by the physicist Freeman Dyson in *Technology Review* encapsulates every aspect of biological postmodernism:

> The epoch of species competition came to an end about 10 thousand years ago when a single species, *Homo sapiens*, began to dominate and reorganize the biosphere. Since that time, cultural evolution has replaced biological evolution as the driving force of change. . . . And now, in the last 30 years, *Homo sapiens* has revived the ancient pre-Darwinian practice of horizontal gene transfer, moving genes easily from microbes to plants and animals, blurring the boundaries between species. We are moving rapidly into the post-Darwinian era, when species will no longer exist, and the evolution of life will again be communal. . . . In the post-Darwinian era, biotechnology will be domesticated. There will be do-it-yourself kits for gardeners, who will use gene transfer to breed new varieties of roses and orchids. Also, biotech games for children, played with real eggs and seeds rather than with images on a screen. Genetic engineering, once it gets into the hands of the general public, will give us an explosion of biodiversity. Designing genomes will be a new art form, as creative as painting or sculpture. Few of the new creations will be masterpieces, but all will bring joy to their creators and diversity to our fauna and flora.[118]

Possibly his avowed Christian faith has convinced Dyson that the deity would not let us mess things up too badly. A century of experience with increasingly powerful technologies, however, suggests that such belief is ill placed.

Beyond Freeman Dyson's dangerously naïve but sweet-tempered invocation of a genetic utopia lies biological postmodernism's "hammers of the witches." Like the so-named fifteenth-century handbook for prosecuting evil-doers, *Malleus maleficarum*, this recent genre seeks to stigmatize critics of its defended doctrine (genetic engineering, in this case) by accusations of nature worship.[119] Although writers in this mode tend themselves to assume a worshipful stance toward "science" (actually a set of sometimes conflicting practices rather than a uniform entity) primarily, many claim, for its supposed capacity to criticize itself, they seem to be particularly disinclined to confront scientific-based criticisms of their preferred technologies. Of course, warnings about nuclear waste and weapon proliferation, chemical pollution, environmental degradation, loss of animal habitats and species, and global warming (all products or outcomes of the best science and technologies of their times) were first raised by people knowledgeable in these fields. But instead of inviting scrutiny of genetic technologies, modern-day hammerers such as Princeton University's Lee Silver and Henry I. Miller, a former U.S. Food and Drug Administration official and a current fellow of Stanford University's corporate-funded Hoover Institution, prefer caricature and contempt. Miller, for example, refers to scientist-critics of the genetic engineering of crops, for example, as "professional agitators."[120] It is this arrogant and defensive attitude of its promoters more than its scientific misconceptions that highlights the ideological nature of the postmodern take on biology.

Finally, as welcome as genuine scientific examination of the latest commercial fixes might be, judgments concerning the wisdom of proceeding with one or another transformative technology raise issues well beyond those discussed in the present paper. Among the most important are the irrationalities of the capitalist system as a whole in its relation to the natural world.[121] But even confining ourselves to the scientific questions discussed here, it is clear that many of the debates around the potentially positive and negative consequences of genetic and other biotechnologies involve concepts of nature and the natural that extend beyond any one discipline. With respect to the biological world, knowledge of how organisms are organized, how they develop, and how their organization and development have evolved is the necessary base for understanding the nature of living things. Only with such understanding can we reasonably discuss what might be desirable to keep or to change. Unfortunately, classic neo-Darwinism, with its excessive theoretical reliance on the agency of genes, is not a reliable guide to the nature of life. Only as a multileveled, integrative theory of biological organization and change becomes more established in the public arena will it become possible to overcome the paradoxical dualism of our time, in which different groups on the one hand exaggerate and on the other reject the efficacy of biological science, while transformation of living nature proceeds apace.[122]

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[1] William Bateson, *William Bateson, F. R. S., Naturalist: His Essays and Addresses* (Cambridge, U.K.: Cambridge University Press, 1928).
[2] Mark Greene, Kathryn Schill, Shoji Takahashi, et al., "Ethics: Moral Issues of Human-Nonhuman Primate Neural Grafting," *Science* 309 (2005):385–386.
[3] Paul Gross, Norman Levitt, and Martin Lewis, *The Flight from Science and Reason* (New York: New York Academy of Sciences, 1996); Noretta Koertge, *A House Built on Sand: Exposing Postmodernist Myths about Science* (New York: Oxford University Press, 1998).
[4] Nuffield Council on Bioethics, *Genetically Modified Crops: The Ethical and Social Issues* (London: Nuffield Council on Bioethics, 1999), 15, available at: http://www.nuffieldbioethics.org/fileLibrary/pdf/gmcrop.pdf.
[5] Any conception of "nature" apart from human activity must also include the material and social cultures of nonhuman animals. For differeing views on the value of untransformed nature, see Bill McKibben, *The End of Nature* (New York: Random House, 1989); McKibben, *Enough: Staying Human in an Engineered Age* (New York: Henry Holt, 2003); Virginia I. Postrel, *The Future and Its Enemies: The Growing Conflict over Creativity, Enterprise, and Progress* (New York: Free Press, 1998); Ray Kurzweil, *The Singularity Is Near: When Humans Transcend Biology* (New York: Viking, 2005); Jeremy Rifkin, *The Biotech Century: Harnessing the Gene and Remaking the World* (New York: Jeremy P. Tarcher/Putnam, 1998).
[6] Keekok Lee, *The Natural and the Artefactual: The Implications of Deep Science and Deep Technology for Environmental Philosophy* (Lanham, Md.: Lexington Books, 1999).
[7] See Nuffield Council on Bioethics, *Genetically Modified Crops.*
[8] An agricultural scientist: Nina V. Fedoroff, "Agriculture: Prehistoric GM Corn," *Science* 302 (2003):1158–1159. Policy analysts: Henry Miller and Gregory Conko, *The Frankenfood Myth: How Protest and Politics Threaten the Biotech Revolution* (Westport, Conn.: Praeger, 2004).
[9] See Allen Buchanan, Dan W. Brock, Norman Daniels, and Daniel Wikler, *From Chance to Choice: Genetics and Justice* (Cambridge, U.K.: Cambridge University Press, 2000).
[10] It can be argued that neo-Darwinism, the reigning paradigm in evolutionary theory for more than half a century, is an important progenitor or "boundary condition" of the postmodernism of cultural theory. I return to this in a later section. See Gerd Müller and Stuart A. Newman, "The Innovation Triad: An EvoDevo Agenda," *Journal of Experimental Zoology. Part B. Molecular*

and Developmental Evolution 304 (2005):487–503; Stuart A. Newman and Gerd Müller, "Genes and Form: Inherency in the Evolution of Developmental Mechanisms," in *Genes in Development: Re-Reading the Molecular Paradigm*, ed. Eva M. Neumann-Held and Christoph Rehmann-Sutter (Durham, N, C.: Duke University Press, 2005), 38–73.

[11] Miller and Conko, *Frankenfood Myth.* See also Lee Silver, *Challenging Nature: Science in a Spiritual World* (New York: Ecco, 2006).

[12] David Noble, *The Religion of Technology: The Divinity of Man and the Spirit of Invention* (New York: Knopf, 1997); Mary Midgley, *Science as Salvation: A Modern Myth and Its Meaning* (London and New York: Routledge, 1992).

[13] Terry Eagleton, *After Theory* (New York: Basic Books, 2003) 58.

[14] On the resistance of scientists, see Josh Schollmeyer, "Minority Report," *Bulletin of the Atomic Scientists* 61 (January/February 2005):38–39.

[15] The reality was different. Eugenics, the attempt to improve human heredity by social policy, was a prestigious research agenda in the United States and Great Britain in the first half of the twentieth century, and forced sterilizations motivated by these ideas were performed throughout North America and Scandinavia at least through the 1970s. The exclusive association of eugenics and eugenicist policies with the Nazis, though the received view throughout the post–World War II period, is a vast oversimplification. See Daniel J. Kevles, *In the Name of Eugenics: Genetics and the Uses of Human Heredity* (New York: Knopf, 1985); Elof Axel Carlson, *The Unfit: The History of a Bad Idea* (Cold Spring Harbor, N.Y.: Cold Spring Harbor Laboratory, 2001).

[16] The Green Revolution was a program initiated by the Rockefeller Foundation in Mexico in 1944 that subsequently spread into South and Southeast Asia, involving improved crop seeds and extensive use of chemical fertilizers, herbicides, and pesticides. It is credited with saving hundreds of millions of people from starvation.

[17] Lysenkoism was the Soviet doctrine, common from the 1930s through the mid-1960s but ultimately considered to have little scientific basis, that biological traits can be altered by physiological means in a fashion that can be passed on to subsequent generations. It declared genetics a "bourgeois pseudoscience" and promoted nongenetic techniques, such as exposure of seeds to cold and fertilizers, to increase agricultural yields.

[18] For technology's impacts among the poor, see Vandana Shiva, *Stolen Harvest: The Hijacking of the Global Food Supply* (Cambridge, Mass.: South End Press, 1999). The Green Revolution, for example, increased the number of dispossessed people and reduced biodiversity.

[19] Ian Hacking, *The Social Construction of What?* (Cambridge, U.K.: Cambridge University Press, 1999); Eagleton, *After Theory*.

[20] David J. Hess, *Science Studies: An Advanced Introduction* (New York: New York University Press, 1997); Alan H. Goodman, Deborah Heath, and M. Susan Lindee, eds., *Genetic Nature/Culture: Anthropology and Science beyond the Two-Culture Divide* (Berkeley: University of California Press, 2003).

[21] Jean Baudrillard, *Simulacra and Simulation***,** trans. Sheila Faria Glaser (Ann Arbor: University of Michigan Press, 1994); Richard Rorty, *Truth and Progress* (Cambridge, U.K., and New York: Cambridge University Press, 1998). There are many definitions and characterizations of postmodernism. While my presentation here draws heavily on the critical views of this phenomenon in Jameson and Eagleton, I am not unsympathetic to the useful ironical and other rhetorical aspects of the querying of received social realities by some postmodernist theorists and

artists. See Fredric Jameson, *Postmodernism, or, the Cultural Logic of Late Capitalism* (Durham, N.C.: Duke University Press, 1991); Eagleton, *After Theory*.

[22] Bruno Latour, *Politics of Nature: How to Bring the Sciences into Democracy* (Cambridge, Mass.: Harvard University Press, 2004).

[23] For resistance from the political right, see Paul Gross and Norman Levitt, *Higher Superstition: The Academic Left and Its Quarrels with Science* (Baltimore: Johns Hopkins University Press, 1994). For resistance from scientists, see Alan D. Sokal and Jean Bricmont, *Fashionable Nonsense: Postmodern Intellectuals' Abuse of Science* (New York: Picador USA, 1998). For resistance from cultural critics, see Jameson, *Postmodernism*; Eagleton *After Theory*.

[24] Eagleton *After Theory*, 67–68.

[25] Reviewed in Stuart A. Newman, "The Fall and Rise of Systems Biology," *Genewatch* 16 (2003):8–12.

[26] Francis Bacon, *The Advancement of Learning and New Atlantis* (Oxford: Oxford University Press, 1979).

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[28] For example, see Steven Pinker, *The Blank Slate: The Modern Denial of Human Nature* (New York: Viking, 2002); Jon Entine, *Taboo: Why Black Athletes Dominate Sports and Why We Are Afraid to Talk about It* (New York: Public Affairs, 2000).

[29] For example, see John Dupré, "Making Hay with Straw Men: Review of Steven Pinker, *The Blank Slate: The Modern Denial of Human Nature*," *American Scientist* 91 (2003):69–72.

[30] Jeff Sessions, September 12, 2005, Testimony of U.S. Senator Jeff Sessions (R-AL) on Day 1 of hearings on the nomination of John Roberts to be Chief Justice of the U.S. Supreme Court, available at http://www.washingtonpost.com/wp-dyn/content/article/2005/09/13/AR2005091300693_pf.html.

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[35] I am not suggesting that agribusiness has refrained from attempting to make modifications that would make produce more appealing to the end user and thus more competitive. Rather, the determinants of quality have proved elusive and difficult to manipulate by genetic engineering.
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[78] Lee M. Silver, *Remaking Eden: How Genetic Engineering and Cloning Will Transform the American Family* (New York: Avon, 1998); Gregory Stock, *Redesigning Humans: Our Inevitable Genetic Future* (Boston: Houghton Mifflin, 2002); Francis Fukuyama, *Our Posthuman Future: Consequences of the Biotechnology Revolution* (New York: Profile Books; Farrar Straus & Giroux, 2002); Buchanan et al., *From Chance to Choice*.
[79] Greene et al., "Ethics: Moral Issues."
[80] Nato Thompson, *Becoming Animal: Contemporary Art in the Animal Kingdom* (North Adams, Mass. and Cambridge, Mass.: Massachusetts Museum of Contemporary Art, distributed by MIT Press, 2005).
[81] David L. Hull, "The Effect of Essentialism on Taxonomy: Two Thousand Years of Stasis," *British Journal for the Philosophy of Science* 15 (1965):314–326, 16:311–318; Ernst W. Mayr, *The Growth of Biological Thought: Diversity, Evolution, and Inheritance* (Cambridge, Mass.: Belknap, 1982).
[82] Robert A. Wilson, ed., *Species: New Interdisciplinary Essays* (Cambridge, Mass.: MIT Press, 1999); specifically in that volume, Richard Boyd, "Homeostasis, Species, and Higher Taxa," 141–186; Paul Griffiths, "Squaring the Circle: Natural Kinds with Historical Essences," 209–228; Robert A. Wilson, "Realism, Essence, and Kind: Resuscitating Species Essentialism?" 187–207. See also Stuart A. Newman and Gerd B. Müller, "Epigenetic Mechanisms of Character Origination," *Journal of Experimental Zoology. Part B. Molecular and Developmental Evolution*, 288 (2000):304–317.
[83] Some material in this section appeared in a different form in Stuart A. Newman, "Evolution: the Public's Problem and the Scientists'," *Capitalism Nature Socialism* 19 (2008): 98-106.
[84] Reviewed in Eugenie C. Scott, *Evolution vs. Creationism: An Introduction* (Westport, Conn.; London: Greenwood, 2004).
[85] Michael J. Behe, *The Edge of Evolution: The Search for the Limits of Darwinism* (New York: Free Press, 2007).
[86] Michael Ruse, *The Evolution Wars: A Guide to the Debates* (Santa Barbara, Calif.: ABC-CLIO, 2000); Robert Wright, "Meaning of Life TV," series of interviews, *Slate.com*, 2006, available at: http://meaningoflife.tv; Freeman Dyson, "Religion from the Outside," *New York Review of Books* 54 (2006):4–8; Francis S. Collins, *The Language of God: A Scientist Presents Evidence for Belief* (New York: Free Press, 2006).
[87] The title of the unpublished essay 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." The malleability of organismal type, despite experience to the contrary, remains a tenet of the neo-Darwinian synthesis. See Alfred Russel Wallace, "On the Tendency of Varieties to Depart Indefinitely from the Original Type," *Proceedings of the Linnean Society of London* 3 (1858):53–62.
[88] George Monbiot, "A Life with No Purpose," *The Guardian* (London), August 16, 2005.
[89] Richard Dawkins, *The God Delusion* (Boston: Houghton Mifflin, 2006).

[90] I am not suggesting here that conclusions about ultimate meaning are within the purview of natural science. Rather, my point is that the assertion that people must relinquish their sense of life's meaning because (1) this is what Darwinism implies, and (2) Darwinism provides a satisfactory account of evolution will not be a persuasive recruiting technique for evolution skeptics if neither of these two things is the case.

[91] Jonathan Weiner, *The Beak of the Finch: A Story of Evolution in Our Time* (New York: Knopf, 1994).

[92] Reviewed in Müller and Newman, "Innovation Triad."

[93] Niles Eldredge and Stephen J. Gould, "Punctuated Equilibria: An Alternative to Phyletic Gradualism," in *Models in Paleobiology*, ed. T. J. M. Schopf (San Francisco: Freeman Cooper, 1972), 82–115.

[94] Stephen Jay Gould, "Darwinian Fundamentalism," *New York Review of Books* 44 (1997):34–37.

[95] Olivier Pourquié, "The Segmentation Clock: Converting Embryonic Time into Spatial Pattern," *Science* 301 (2003):328–330.

[96] Small gene-associated 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. See examples in Müller and Newman, *Origination of Organismal Form.*

[97] Gabor Forgacs and Stuart A. Newman, *Biological Physics of the Developing Embryo* (Cambridge, U.K.: Cambridge University Press, 2005).

[98] Newman and Müller, "Epigenetic Mechanisms"; Mary Jane West-Eberhard, *Developmental Plasticity and Evolution* (Oxford and New York: Oxford University Press, 2003).

[99] C. H. Waddington, "Canalization of Development and the Inheritance of Acquired Characters," *Nature* 150 (1942):563–565.

[100] "Self-organization" is a term used to describe the capacity of certain materials, nonliving as well as living, to assume preferred forms by virtue of their inherent physical properties. For applications of this concept to developing embryos, see Forgacs and Newman, *Biological Physics.* On the Cambrian explosion, see Stephen Jay Gould, *Wonderful Life: The Burgess Shale and the Nature of History* (New York: WW Norton, 1989).

[101] Jean M. Carlson and John Doyle, "Complexity and Robustness," *Proceedings of the National Academy of Science U.S.A.* 99 Suppl. 1 (2002):2538–2545.

[102] Massimo Pigliucci, *Phenotypic Plasticity: Beyond Nature and Nurture* (Baltimore, Md.: Johns Hopkins University Press, 2001); West-Eberhard, *Developmental Plasticity.*

[103] I owe this insight to Prof. Marion Blute. See Charles Darwin, *On the Origin of Species by Means of Natural Selection, or, The Preservation of Favoured Races in the Struggle for Life* (London: J. Murray, 1872 [1859]).

[104] For a review, see Stuart A. Newman, "The Pre-Mendelian, Pre-Darwinian World: Shifting Relations Between Genetic and Epigenetic Mechanisms in Early Multicellular Evolution," *Journal of Bioscience* 30 (2005):75–85.

[105] Daniel C. Dennett, *Darwin's Dangerous Idea: Evolution and the Meanings of Life* (New York: Simon & Schuster, 1995).

[106] 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.

[107] See note 17 on Lysenkoism.

[108] B. Zavadovsky, "The 'Physical' and the 'Biological' in the Process of Organic Evolution," in *Science at the Crossroads*, ed. Nikolai Bukharin (London: Frank Cass, 1931) 69–80; Richard Levins and Richard C. Lewontin, *The Dialectical Biologist* (Cambridge, Mass.: Harvard University Press, 1985).

[109] Christiane Nüsslein-Volhard, *Coming to Life: How Genes Drive Development* (New Haven, Conn.: Yale University Press, 2006).

[110] For example, see Geerat J. Vermeij, *Evolution and Escalation: An Ecological History of Life* (Princeton, N.J.: Princeton University Press, 1987); Weiner, *Beak of the Finch;* Michael Pollan, *The Botany of Desire: A Plant's Eye View of the World* (New York: Random House, 2001); Carl Zimmer, *Evolution: The Triumph of an Idea* (New York: HarperCollins, 2001). As they are contemporary works, "gene-language" pervades these writings, but this is not their main subject.

[111] Mary Midgley, *Evolution as a Religion: Strange Hopes and Stranger Fears* (London and New York: Methuen, 1985); Michael Ruse, *The Evolution-Creation Struggle* (Cambridge, Mass.: Harvard University Press, 2005).

[112] Brian Charlesworth, "Evolution: On the Origins of Novelty and Variation" (review of Marc W. Kirschner and John C. Gerhart, *The Plausibility of Life: Resolving Darwin's Dilemma*), *Science* 310 (2005):1619–1620.

[113] Orthogenesis, the idea that evolving systems have an innate tendency to change in certain preferred directions, is generally condemned by neo-Darwinists. But the EvoDevo conclusion that there are preferred forms for living tissues dictated by their inherent material properties (see the segmentation example, above) provides a rationale for a concept of orthogenesis that is entirely consistent with modern biology.

[114] Edward O. Wilson, *The Diversity of Life* (Cambridge, Mass.: Belknap Press, 1992).

[115] Kerri Smith, "Homing in on the Genes for Humanity," *Nature* 442 (2006):725.

[116] Francis Crick, *Life Itself: Its Origin and Nature* (New York: Simon and Schuster, 1981).

[117] The phrase "context of no context" was coined by the late cultural critic George W. S. Trow, who used it in reference to popular culture. See George W. S. Trow, *Within the Context of No Context* (Boston: Little, Brown, 1981).

[118] Freeman Dyson, "The Darwinian Interlude," *Technology Review* March 2005, available at http://www.technologyreview.com/read_article.aspx?id=14236&ch=biotech. An expanded version of this piece subsequently appeared in Freeman Dyson, "Our Biotech Future," *New York Review of Books* 54 (2007):4–8.

[119] See Silver, *Challenging Nature*.

[120] Miller and Conko, *Frankenfood Myth*.

[121] Lee, *Natural and the Artefactual*; Joel Kovel, *The Enemy of Nature: The End of Capitalism or the End of the World?* (London: Zed Books, 2002).

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102 Getting Past Postmodernism in the Life Sciences. heads of nonhuman primates, ï¬rst dispensing with distractions: â€˜â€˜We. unanimously rejected ethical objections grounded on unnaturalness or.Â 104 Getting Past Postmodernism in the Life Sciences. essentially nihilistic set of views is increasingly taken as the hallmark of an. informed secularism by libertarians and many liberals. The science of biology shapes everything from agriculture to psychology. And like most sciences, biology is rapidly advancing due to advances in technology, which are changing the field forever. In the past 25 years, weâ€™ve seen some amazing things. In this article, weâ€™re going to explore the latest and greatest discoveries.Â In the early 1990s, biologists started getting some odd results when trying to manipulate gene expression. The most striking example of this was in a study about petunias. Plant biologists were trying to intensify the red color on the flower petals by introducing a gene that induced the formation of a red pigment, but were surprised to discover that their efforts turned the flower entirely white.