

Darwinism and Traditional Theology

Darwinian evolutionary theory offered a view of life diametrically different from that of traditional Judeo-Christian theology. The biblical six days of creation were thought to have taken place only a few thousand years ago. Today, scientists maintain that the universe is about 10,000 - 20,000 million years old, the earth is about 4,500 million years old, and life arose about 3,500 million years ago; hominids resembling our species appeared 4 million years ago, and our species, *Homo sapiens* appeared about 130,000 years ago.

According to traditional natural theology, the world is static: God had formed all species just as they appear today. And there is no genealogical relationship between them. There had been great cataclysms such as the biblical flood, but Noah had saved all the species living today. This static view was also shared by the great philosophers of ancient Greece. In the Aristotelian and the Platonic order of things life forms were ordered in single file from the most simple inanimate objects, to plants, then to lower and higher animals- as a fixed plan of creation. The increasing perfection in this *scala naturae* or “Great Chain of Being” was understood in terms of different kinds of “soul”, more reason, greater advance toward God.¹ In contrast to the great chain of being, Darwinian evolutionary theory holds that all life is related and that genealogical relations between species resemble, not a ladder, but a complex branching tree.

Naturalists before Darwin who had grouped plants and animals into species, genera and families, had believed their natural system revealed “the plan of the Creator.” But their order of things assumed a new significance in the light of evolutionary theory. All the innumerable species, genera, and families of organic beings, descended, each within its own class or group, from common parents, and all had been modified in the course of descent. As Darwin wrote “all plants and animals have descended from one common prototype” and that “probably all organic beings which have ever lived on this earth have descended from some one primordial form, into which life was first breathed.”²

The Natural theologians of the 18th and 19th centuries insisted that the complexity and harmony of a plant or an animal and its place in nature has been designed by its creator. Natural processes could not have led to the production and reproduction of such complex structures as the eye or the

Human evolution: Darwinism, genes and germs

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Resumo

A evolução é um processo complementar de divergência e integração. A simbiose, integração fisiológica e/ou genética dos grupos taxonómicos é reconhecida, actualmente, como estando na base de mudanças macroevolutivas. Considera-se que teve um papel central na evolução dos eucariotas, na origem das plantas terrestres e numa miríade de inovações evolutivas adaptativas. Numa perspectiva simbiótica de que cada planta e cada animal é um superorganismo, um simbioma abrange os genes cromossómicos, os genes organelares e frequentemente outros simbiotes bacterianos, bem como vírus. O simbioma estende-se para além das actividades das suas “próprias” células. A análise da sequenciação nucleotídica revitalizou a filogenia microbiana, fortalecendo ainda mais uma visão da vida na Terra centrada no micróbio, e o papel da simbiose na evolução. Nos últimos oito anos, a análise genómica também indicou uma intensa permuta de genes entre bactérias: quando tomados em conjunto com a simbiose, estes dados contradizem vários princípios fundamentais da síntese neo-Darwiniana.

To help to set a framework for our discussions in this forum on science, religion and consciousness, I begin by summarizing how Darwinian evolutionary theory contrasts with traditional Judeo-Christian beliefs, and the Darwinian’s conceptual reformation of the place of humans in nature. I then point to fundamental flaws with a gene-centred view of humans and culture. I comment on some limitations of human genomics, and finally shift to the microbial world, and the concept of the symbiome. If I had an alternative title it would be “Whose planet is this anyway?”

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human brain, nor of co-adaptations as of insects and flowers. The complexity of plants and animals, as well as the harmonious mutualistic relations between species, were evidence of the wisdom and benevolence of a creator. In the Darwinian world view, there is no design in the natural world, no pre-conceived plan. Organisms evolve in a make-shift or contingent manner in relation to changing ecological conditions. The appearance of a species results from numerous forces which combine at a certain epoch in a certain place. Had the conditions been different, the natural world would be different today: nothing is necessary, nothing is pre-planned, and nothing therefore is beyond investigation.

Darwin postulated that evolutionary change occurred by a struggle for existence giving rise to a natural selection of the most fit. Evolution was a two-step process resulting from chance and necessity: 1) the production of variation, and 2) subsequently natural selection, the preservation of favorable variations and the rejection of injurious variations. He looked to artificial selection by breeders of domesticated plants and animals for a model. Breeders were able to select those varieties of particular interest to them. They did not act directly to produce the variability itself, but heritable modifications appeared occasionally; they appeared “randomly,” and were selected purposefully.

Checks on population growth provided the conditions for selection to operate, and Darwin drew on Thomas Malthus’s essay to underscore the intensity and persistence of life-struggle because there was a tendency in nature for more offspring being produced than could survive. As Darwin concluded the *Origin*, “Thus from the war of nature, from famine and death, the most exalted objects which we are capable of conceiving, namely, the production of higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved.”³

Evolutionary theory and rationalist explanation do not necessarily preclude the concept of God: some evolutionists may be agnostic or they may invoke God to explain the origins of the natural laws through which life evolves. “Darwin’s bulldog,” Thomas Henry Huxley coined the term “agnostic” when he wrote about theology and philosophy. Most of his polemics were directed at the anti-intellectualism of the church dogma. He

introduced the term “agnostic” as “suggestively antithetic to the Gnostic” of Church history, who professed to know so very much. Agnosticism, for Huxley was not a creed; it was an injunction about the way of approaching knowledge: to follow reason as far it could go without consideration for where it might lead, and not to pretend to know things with certainty which have not been demonstrated or are not demonstrable.⁴

By introducing contingency in nature, the theory of natural selection displaced God but did not necessarily replace a First Cause. In October, 1996 the Pope announced that evolution did indeed have scientific support. The Roman Catholic church has officially accepted evolution as long as it doesn’t exclude God from the creative process, in particular from the creation of the human soul. Darwin himself recognized that there may well be a “First Cause having an intelligent mind in some degree analogous to that of man.” However, he considered such matters to be beyond the intellectual reach of man. As he wrote in a letter of 1879:

But then arises the doubt - can the mind of man, which has, as I fully believe, been developed from a mind as low as that possessed by the lowest animals, be trusted when it draws such grand conclusions?

I cannot pretend to throw the least light on such abstruse problems. The mystery of the beginning of all things is insoluble by us, and I for one must be content to remain an Agnostic.⁵

The Place of Humans in Nature

Traditional Judeo-Christian theology placed humans outside and above nature. Accordingly, we were formed in the image of God and were given dominion over nature. Darwinian evolutionary theory places humans within nature, as members of the animal “kingdom.” Just as Copernicanism displaced the earth from the centre of the universe, Darwin’s theory displaced the human from the centre of the earth. At least this was/is the claim, but in reality the first generation of Darwinian evolutionists thought in anthropocentric terms of progressive evolution leading to humans.

Darwin avoided much mention of human evolution in *the Origin* of 1859, stating only in the conclusion that in research fields that would open up, “Light will be thrown on the origin of man and his history.”⁶ He discussed human evolution in detail twelve years later in *The Descent of Man*

(1871).⁷ Thomas Henry Huxley's *Man's Place in Nature* (1863) was the first comprehensive overview of about primate and human palaeontology and ethology.⁸ It was also the first attempt to apply evolution explicitly to humans. "The question of questions for mankind - the problem which underlies all others, and is more deeply interesting than any other," he wrote,

is the ascertainment of the place which man occupies in nature and of his relations to the universe of things. Whence our race has come; what are the limits of our power over nature and of nature's power over us; to what goal we are tending; [these] are the problems which present themselves anew and with undiminished interest to every man born into the world. Most of us, shrinking from the difficulties and dangers which beset the seeker after original answers to these riddles, are contented to ignore them altogether, or to smother the investigating spirit under the featherbed of respected and respectable tradition⁹

Although humans were part of nature, humans created culture, and it, in turn, has its own history. Yet, ever since Darwin, there have been evolutionists who have treated organic evolution and human social relations as one subject. In fact, what we call "Darwinism" represented a naturalistic approach to life, our place in nature, our ethics and our societies. The use of natural law as the basis for a given view of society was commonplace in social, political and economic theory.¹⁰ The extent to which human social relations are determined by natural evolutionary processes remains a cause of fierce disagreement today.

Evolution for many nineteenth century thinkers implied progress in nature and society. This meant that "the struggle for existence," that is, conflict and competition, should be encouraged for the progress of humankind. But exactly how this should be applied was not straightforward. Darwinian theory was summoned to support all types of political and ideological positions from the most reactionary to the most progressive. Whatever their political inclinations, writers often drew on evolutionary theory and "the laws of nature" to bolster their views. Though conceived of as a secular saint, and protected from any ideological taint, historians have shown that Darwin himself was also a "social Darwinist." And in the *Descent of Man* (1868) he applied the struggle for existence to human social history, a survival of the superior races over others.

The arguments from nature to human society are somewhat circular because Darwinian theory was itself embedded in social economic theory.

In fact, some scholars have gone so far as to assert that "Darwinism was an extension of laissez-faire economic theory from social science to biology."¹¹ Moreover, although for the first generation of Darwinians, evolution implied progress, modern evolutionists insist that words such as "progress" or "improvement" are inappropriate because their criteria remain ill defined. If one criterion of progress is adaptation, then bacteria are at least as adapted as humans. Yet, the problem of progress remains a serious one for many evolutionists.

Understanding human society in terms of Darwinian evolution continues today under the guise of sociobiology, and its recent offspring "evolutionary psychology" which tends to view every human trait as having an adaptively evolved present purpose, shaped by natural selection. Sociobiologists turn evolution into a sort of a game in which the object is to maximize an individual's genetic representation in the next generation, –a struggle for existence among "selfish genes." Ethics, aesthetics, politics, culture, war and religion, all fall within the scope of sociobiological inquiry. All are to be put on a firm universal biological, that is, evolutionary, basis.

Harvard entomologist E.O. Wilson's book *Sociobiology the New Synthesis* (1975) ushered in the new field. It was followed by several others which argued for a causal linear link from genes to society, none better known than Richard Dawkins's blockbuster, *The Selfish Gene* (1976). All of Dawkins's arguments were dedicated to the same reductionist point: that cooperation could be explained as a winning strategy, through which an individual, "blindly programmed to preserve selfish genes," can best promote its own survival. Thus, he described humans as "giant lumbering robots" under the control of our genes that "have created us, body and mind."¹² Although a secular book, Dawkins spoke about selfish genes in a manner not unlike the cleric's "original sin": "Be warned that if you wish as I do, to build a society in which individuals cooperate generously and unselfishly towards a common good, you can expect little help from biological nature. Let us try to teach generosity and altruism, because we are born selfish."

These comments came at a time of an environmental awakening, of the need to protect our global environment from the abuses of industrial development. In regard to environmentalism, Dawkins offered a gene's-eye view of short-term self-interest versus cooperation for the common good as portrayed title of Garrett Hardin's famous essay of 1968, "The Tragedy of the Commons":

Entities that pay the costs of furthering the well-being of the ecosystem as a whole will tend to reproduce themselves less successfully than rivals that exploit their public-spirited colleagues, and contribute nothing to the general welfare. Hardin (1968) summed the problem up in his memorable phrase 'The tragedy of the commons' and more recently (Hardin 1978) in the aphorism, 'Nice guys finish last.'¹³

Improving our environment versus advancing our "selfish genes" continued to be addressed in a *fin-de siècle* best-seller *The Spirit of the Gene*, endorsed by leading biologists including E.O. Wilson; it is argued that the notion of cultural influence on human behavior is an illusion and talk of "cultural history is misleading."¹⁴ Culture, it is asserted, is merely a "genetic feedback mechanism" designed to fool us into believing that genes are not in control. "Morality is a shrewdly fashioned genetic propaganda device designed to heighten our mystical gullibility and conceal from us the real source of our behavior, of both heroes and villains- our genes."¹⁵ Capitalism is a "genetic imperative." Our species is thus destined to destroy itself through over-population, technological growth and consumerism, and there is nothing we can do about it because it's not a question of values, politics, economics or social history, it's in our genes, our evolution. Thus, the author intimates that we actually live in a virtual reality constructed by a computer-like program running in our DNA. These pernicious assertions, of course, amount to irrefutable metaphysics, since all arguments to the contrary would be neither mine nor yours, but merely the author's predicted response of our genes.

Biological determinism, the advocacy of a chain of causality from genes to society, has been debunked from many sides.¹⁶ Critics argue that the forms of human societies are only remotely associated with our genes, and that it is absurd to conceive of human cultural history as a by-product of our genes, as an evolutionary product of natural selection. They protest that the biological determinists' conjectures and concepts transcended science, and that they only reflected and reinforced a conservative establishment, and serve to stifle social reform.¹⁷ Sociobiologists' evolutionary reasoning was fundamentally flawed on three grounds.

1) The notion that individual genes are made visible to selection because of their more or less direct one-to one relationship with particular phenotypic features was an integral feature of the sociobiological approach. However, an individual gene is seldom directly exposed to selection, but

usually in the context of its entire genotype, and since a gene may have different selective values in different genomic contexts, it is highly unsuitable as the target of selection. Thus, the individual organism, the phenotype, is the main target of selection, not the gene.¹⁸ This issue has become only more salient as molecular biologists understand the complex relations between genes and phenotypes, and as the very concept of the gene has become ever more abstract.

2) Sociobiologists tend to treat every evolved trait as if it were an adaptive trait; ie. the product of selection.¹⁹ But one cannot simply assume that a structure arose for the present purpose, nor that it had an adaptive purpose then or now and had therefore evolved by natural selection. Appreciating this point is also important for understanding the early evolution of complex organs such as the wings of a bird or insect, before they were used for flying, proto-wings had other purposes.²⁰ Evolutionists sensitive to the adaptationist fallacy have invoked Voltaire's Dr. Pangloss "Things cannot be other than they are, for since everything was made for a purpose, it follows that everything is made for the best purpose. Our noses were made to carry spectacles, so we have spectacles. Legs were clearly intended for breeches, and we wear them."²¹

3) Sociobiologists' views are based on identifying features common to all human societies, invoking genes to explain them, and then making up a story about how they evolved. Insisting that the gene is the primary target of selection, sociobiologists often invoke "a gene for this" and "a gene for that." Dawkins, for example referred to "the kin-altruism gene."²² Stephen Jay Gould launched one of the strongest critiques of sociobiologists' accounts when he argued that, in their art of story-telling, sociobiologists often fall prey to the temptation to tell "just-so stories" with no more validity than Rudyard Kipling's creative fairy tales about how the leopard lost its spots, how the camel got its hump, how the elephant got its trunk.²³

What makes us human is a large plastic brain that allows many possibilities for our future. We have constructed ourselves, and can reconstruct ourselves and cultures in many ways.

The Human Genome

Gene-centred views of our selves and culture continue to capture public and scientific imagination. In 1990, the U.S. Human Genome Project

began as a fifteen-year effort coordinated by the Department of Energy and the National Institutes of Health. Its aims were to identify all the genes in human DNA, determine the sequence of its three billion nucleotides, store this information in databases, improve tools for data analysis, transfer related technologies to the private sector, and address the ethical, legal, and social issues that may arise from the project.

In June 2000, a working draft of the entire human genome sequence was announced, with analyses published in February 2001. The hyperbole about self-knowledge was boundless.²⁴ Lets look at the stories written by scientists and journalists. The human genome has been referred to as the “book of man,” the “holy grail.” Knowledge of it promises to reduce human suffering caused by genetic diseases due to single-gene defects, cystic fibrosis, and sickle cell anemia, among others. The ability to screen for genes and analyze them directly would open up a new medical era of gene therapy, and products derived from genome research would boost the international pharmaceutical business. By licensing technologies to private companies and awarding grants for innovative research, the human genome project would catalyze the multibillion-dollar U.S. biotechnology industry.

The sequencing of the genome was likened to landing on the Moon, splitting the atom and inventing the wheel. The code, it was said, will tell us what distinguishes us from other species, what makes us human; it has been considered to be “the secular equivalent of the soul, our inner stable true nature throughout our individual lives.”²⁵ The most profound social, ethical and legal issues permeate the “brave new world” with old ones about eugenics reconsidered and new ones over human gene patents, genetic screening, and concern that knowledge of an individual’s genome be kept from employers, insurance companies, as well as governments, no matter how apparently benign or benevolent.²⁶

Reports and speculations about genes for violence, for depression, for impulsiveness, for novelty seeking, for alcoholism, and homosexuality have permeated public consciousness. No sooner has one group of researchers tied a gene to a behavior when along comes the next study asserting that the link is bogus or even that the gene in question has exactly the opposite effect.²⁷ Debates have often become polarized between genetic determinism on the one hand and cultural determinism on the other. Untangling the effects of genes from their social context is hazardous.

Critics of genetic determinism have probed various social aspects of “the DNA mystique,” to understand the cultural fixation with genes.²⁸ When

emphasizing the roles of the environment and culture, however, they commonly assume that our heredity is solely a matter of our genome. That DNA is a “genetic program” theoretically capable of creating an organism, even when operating within the egg of a different species, is the premise for Michael Crichton’s best- seller, and blockbuster movie, *Jurassic Park*. The computer program, once only a metaphor for the genome, is no longer such. We can read that our genetic information, “the essence of our being,” can be stored in computers and reemerge to reproduce ourselves. Marveling over the biotechnological possibilities of the human genome project, the author of a scientifically acclaimed paperback, *The Genome*, introduces his book by asserting that: “You can now download from the Internet the near-complete instructions for how to build and run a human body.”²⁹ All of this hyperbole is far from reality, the relationship between genes, proteins and cells and multi-cellular organism is much more complex than this implies. Indeed, many of those who work on morphogenesis believe it is absurd to think of a genetic program for an organism. Organisms make genes, not the inverse.³⁰

Abstract Genes

That organismic complexity cannot be reduced to the information in the genome was also suggested by one of the most striking and unexpected results of the human genome project: the human genome it is made up of so few genes. At the outset of the project, it was estimated that there would be about 100,000 -140,000 genes. However, by 2001, The Human Genome Sequencing Consortium had spotted 22,000 protein-coding genes, and it was estimated that our genomes contain a mere 30,000 genes.³¹ This is only twice as many genes as a fruit fly and a flatworm, and not as many as rice.³² In terms of gene number we are on a par with *Arabidopsis*, a mustard-like weed (which has 26,000 genes). The 30,000 genes in our genome contradicted the principal scientific premise on which the human genome project was undertaken: that there would be a one-to-one, linear relationship between genes, proteins and genetic disease. Thus, one could detect defective genes from the DNA code. As one of the pioneers of the human genome project, Craig Venter, recalled in 2002, “People so wanted it to be the beginning of the end of everything... One gene, one disease, one treatment.”³³

This was the basis of previous estimates of human gene numbers. However, by the 1980s, molecular biologists had recognized more and more that gene structure and gene expression was more complex than a simple one-to one relation between genes and protein implied.³⁴

Genes have long intervening non-coding sequences, called “introns” between coding regions, called “exons.”³⁵ Before these so called “split genes” could be expressed, the RNA has to be “edited”, the intervening sequences has to be removed by special enzymes, and then spliced back together again. After a DNA sequence is transcribed to messenger RNA often a small body they called a “spliceosome” (or splicing body), a protein-RNA complex, assembles at sites along the mRNA, where it cuts out various segments. When coding regions are spliced together certain exons are excluded from some transcripts and included in others. The remaining pieces of RNA may be spliced together into a number of alternative combinations and these are used as messages (mRNA). Each new nucleotide sequence is different from that coded from the original gene.

Alternatively spliced RNAs code for different proteins.³⁶ As I have described elsewhere it is comparable to a game of “Scrabble” in which, for example, the seven letters STARTLE can be alternatively spliced, in the order in which they appear, to give the words: start, star, stale, sale, tar, tart, tale, and ale. The original informational unit STARTLE, the “gene” is important, but so too is the information in the spliceosome that arranges the message.³⁷ Sapp, 2003

Alternative RNA splicing can have an enormous impact on the gene/protein ratio. One “gene” can give rise to dozens of proteins.³⁸ At first thought to be an exceptional occurrence in humans, by the end of the century it was estimated that about 40% of human genes are alternatively spliced, and this, genomic researchers argue, partially explains the earlier inflated gene number predictions.³⁹

Because of such mechanisms for regulating and modifying protein synthesis, and other post-translational modifications, although there are 30,000 genes, there may be ten times as many proteins in the human body. Not only can one gene have many effects, the reverse is also true: many genes could affect one hereditary trait including genetically-based maladies in humans.⁴⁰ A gene’s effect on inheritance cannot be completely predicted from its nucleotide sequence. And one cannot search for gene-based diseases solely in the primary sequence itself. Many human diseases are caused by

mutations that interfere with RNA splicing.⁴¹ The promise of therapeutic breakthroughs by the map of the genome may not come for decades.⁴²

The complexity of genetic information and its modifications with RNA editing greatly complicated the definition of the “gene.” First defined as simply as a unit of inheritance, and then as a locus on a chromosomes, then as a specific nucleotide sequence of DNA, the definition of a gene has become increasingly abstract. What exactly the gene is has become somewhat unclear.⁴³ Molecular biologists have generally returned to the old concept of the gene, common in the early twentieth century -that genes are operational entities.⁴⁴

Still, there is another reason why we and other organisms cannot be reduced to our chromosomes, and why one cannot even in principle make a dinosaur from DNA: bacterial symbionts.

More than the Genome

We have been led to believe that each of us is a single entity with one major genome in our cell nucleus containing genes transmitted to each of us from our fathers and mothers, and a small mitochondrial genome of about 40 genes, transmitted from our mothers. But this view ignores all the microbes that share our bodies. It is estimated that there are about 10^{14} cells in our bodies, 10% of them are our “own” eukaryotic cells, 90% are bacteria comprising about 400 to 500 “species,” many of which cannot be easily cultured in the laboratory.⁴⁵ They form a sheath on our skin, and they cover the insides of our nose, throat and gut. Twenty to fifty percent of the human colon is thought to be occupied by bacteria. Our mouths contain about eighty kinds of bacteria and our stomach typically contains several hundred species. Although little is known about their interactions, without them in the proper relations we would not be able to function properly. Biologists are just beginning to explore the nature of gut bacteria. Different kinds of bacteria in the human colon are stratified into specific regions in the gut tube. They are picked up as soon as the amnion bursts from the mother’s reproductive tract. Medical science is just beginning to ask questions about how these populations are maintained in our bodies and what they do.

Contemporary research indicates that our cells may be fashioned physiologically and morphologically by our bacterial community which, not

only provides vitamins K and B12, but may regulate many of our own genes and may be crucial in warding off pathogens. The intestines of germ-free mice cannot complete differentiation. They require their gut bacteria for that. And bacteria have been shown to regulate transcription of genes involved in several intestinal functions.⁴⁶ Microbes on and in us defend their own niches against interlopers, and in so doing help protect their host. Forty percent of people have *Helicobacter pylori* in their stomach lining which since the 1980s, has been shown to, once in a while, culminate in an ulcer. But these bacteria also secrete antibiotics that are protection against cholera. There is evidence that even the harmless bacteria on our tongue help to protect us against harmful microbes taken in with our food.⁴⁷ Because of the immunological importance of bacteria, some researchers are reconsidering the centuries-old practice of “probiotics”: eating live bacteria to prevent gut infections and other intestinal problems.⁴⁸

Our views of bacteria have been slanted by an overwhelming pathological perspective of disease causing pathogens. Although bacteria do have an aptitude for making us ill and killing us, they have a shared interest in our survival: A dead host is also a dead end for most infections. Therefore, domesticating the host is the better long-term strategy. If this were not the case, large, morphologically complex organisms like us could never have survived the evolutionary competition with bacteria. So the fundamental evolutionary relationship to our microbial communities tends toward an almost mutualistic equilibrium.

This may be somewhat difficult to understand from our own understandably anthropocentric outlook about the disease-causing effects of bacteria. As Joshua Lederberg commented recently in a lecture at the Brooklyn Law School, there are different statistical points of view about this. Although we consider a catastrophe an infection in which 3 percent of human hosts are killed, to a microbial population such a loss does not really matter very much. Even so, very few microbes will do that. Each of us may also possess our own unique communities of microbes, and the make up of that community may have much to do with an individual’s susceptibility to disease. Lederberg conjectured, “I would venture to say that seventy-five percent of the people in this room are carrying in your nasal passages, in your gut, and in your lungs organisms that have the potential for causing severe disease when they are transmitted to others; and yet we have somehow or other established a most friendly equilibrium.”⁴⁹

As I have detailed elsewhere, although the bacteria living in our bodies have recently begun to attract some medical interest, for most of the twentieth century, research on microbial symbiosis developed close to the margins of the life sciences, and in virtual conflict with the aims and doctrines of the major biological disciplines, as well as medical concepts of germs.⁵⁰

Equipped today with many examples of symbiosis, with diverse physiological and morphological effects, leading researchers urge neo-Darwinian evolutionists to reconsider symbiosis in heredity and development, and as a general mechanism of evolutionary innovation, in addition to gene mutations and recombination.⁵¹ Ideas originating at the end of the nineteenth century, have been recast at the end of the twentieth century, as microbial evolutionist insist that symbiotic mergers, and the transfer of genes between different kinds of bacteria are cardinal mechanisms of evolutionary change.

The Symbiome

Since the early 1970s, biotechnologists have learned to move genes across the phylogenetic spectrum from plants and animals to bacteria and back again. Most of the insulin used to treat diabetes is now obtained from bacteria that contain a human insulin gene. In agricultural applications, cultivated plants and animals are genetically engineered to resist pests and herbicides, and to grow bigger and faster, all using genes from other species. The creation of such “transgenic organisms” has been, and continues to be, a subject of intense controversy involving socio-political and conservation issues.⁵²

Early opponents of this biotechnology argued that the creation of such chimeras is in violation of natural law because genes are not naturally transferred between species. They maintained that evolutionary change always occurs in the most gradual manner. Yet, the transfer of genes between taxonomic groups is known to occur naturally. What opponents to biotechnology could have argued was that when such transfer takes place naturally it may lead to major saltational leaps, not gradual Darwinian creeps.

Many bacterial “species” exchange genes, and many protists, plants, and animals harbor symbiotic bacteria that are transmitted hereditarily from one generation to the next. Biologists also agree today that all eukaryotes

(all nucleated cells like our own) emerged from mergers between different kinds of bacteria.

We humans and all other animals, and plants are already chimeras. The contemporary consensus holds that the mitochondria in the cytoplasm of all eukaryotic cells and the chloroplasts of plants and protists were once free-living bacteria that became incorporated in a primitive host cell some 1800 million years ago.

Mitochondria are the organelles in which cellular respiration take place. Without them we cannot breathe. Their primary function is the combustion of foodstuffs using oxygen to assemble the energy-rich molecule adenosine triphosphate (ATP), the main source of energy in virtually all oxygen-dependent (aerobic) organisms. Chloroplasts are the organelles in plants in which photosynthesis takes place; they collect electromagnetic energy of sunlight to produce organic compounds from water and carbon dioxide, and without them plants do not grow. Mitochondria are thought to have been first acquired as food by predatory microbes, they resisted digestion, and they proved to be of benefit to their host because the primitive atmosphere increased in oxygen, which otherwise would be toxic to their hosts; the engulfed mitochondria detoxified the oxygen. Chloroplasts originated subsequently when a microbe engulfed cyanobacteria. Their selective advantage to the host is obvious: protists that once needed a constant food supply henceforth could thrive on nothing more than light together with air, water, and a few dissolved minerals. Mitochondria and chloroplasts are inherited from one generation to the next through the cell cytoplasm. In the course of evolution, many of their original bacterial genes were lost, and some were transferred to the cell nucleus.⁵³ Recently, many microbial evolutionists consider that the cell nucleus may have also arisen by some sort of fusion of symbiosis between two different kinds of bacteria.⁵⁴ We so-called “higher organisms” did not just evolve from bacteria, we were created and maintained by bacteria.

Classical neo-Darwinian evolutionists like to think that Cambrian explosion is the “big bang” of biology. Most of the fossil record comes from extinct plants and animals which burst onto the scene between 560-495 million years ago, the Cambrian period. Why the Cambrian explosion occurred is not fully understood. But those who study cellular organization insist that the real “big bang” of biology occurred some 1800 million years earlier when the eukaryote arose. With its membrane-bound nucleus and all

the associated features, such as mitosis, meiosis, and multiple chromosomes to package up to tens of thousands of genes per cell, it provided the organismic conditions for the differentiation of tissues, organs and organ systems of plants and animals. Bacteria had only an unpackaged single strand of DNA, holding some four thousand genes. Thus, symbiosis has played a major role in a macro-event in evolution, the origin of the eukaryotic cell.

Hereditary symbiosis is especially common in insects. All aphids carry bacteria of the genus *Buchnera* in their cells and the symbionts are inherited through the host egg.⁵⁵ Each aphid has some five million bacterial symbionts; this relationship developed 250 million years ago, and is obligatory for both bacteria and insect. They cannot live apart.⁵⁶ Microbial symbionts are especially prevalent in sap-sucking, blood-sucking and wood-eating insects for which they provide enzymes, vitamins, energy and sugars.⁵⁷ Termites, leaf-eating insects, and ruminants, would starve to death without the symbionts in their guts to break down cellulose.

Molecular techniques for screening DNA have, so far, found bacteria of the genus *Wolbachia* in more than 16% of all known insect species, including each of the major insect orders.⁵⁸ It is estimated that *Wolbachia* may be present in as many as 80% of all insects. They may be the most common hereditary infection on Earth, rampant throughout the invertebrate world including shrimp, spiders and parasitic worms, as well as insects.⁵⁹ Their complete distribution in arthropods and other phyla are yet to be determined. *Wolbachia* are α -proteobacteria, like mitochondria, and they appear to have evolved as specialists in manipulating reproduction and development of their hosts. They cause a number of profound reproductive alterations in insects, including cytoplasmic incompatibility between strains and related species, parthenogenesis induction, and feminization: they can convert genetic males into reproductive females (and produce intersexes). Sometimes, as in the case of weevils (one of the most notorious pests of stored grain), *Wolbachia* are inherited together with other bacterial symbionts which allow the animal better adaptation to the environment by providing vitamins, and energy, and enhancing the insect's ability to fly.⁶⁰ *Wolbachia* have considerable evolutionary interest, especially as a mechanism for rapid speciation.

Sea anemones, hydra, giant clams, sponges, and the corals that build coral reefs acquire algae from the ocean and harbour them in their cells, and are nourished by their photosynthetically produced carbon compounds.

Corals acquire up to 60% of their nutrition from their algal symbionts (*Symbiodinium*, dinoflagellates), which in return obtain from the coral polyp nitrogenous compounds that are scarce in the crystal-clear tropical waters. In some cases the symbionts are transmitted hereditarily in others they are acquired in each generation. The world-wide crisis of tropical corals today is indicative of what happens when this delicate balance is broken with global climate change and global warming. Prolonged increase in sea-surface temperature, solar irradiation, sedimentation, and inorganic pollutants, cause coral "bleaching": corals lose their algae, leaving their tissues so transparent that only the white calcium carbonate skeleton is apparent. Without the algae, corals starve to death.

In humans (and other mammals), there is no evidence that bacteria are transmitted through the mother's egg. However, the integrated retroviruses (and other processed RNA) into the human genome are indubitable examples of horizontal gene transfer from viruses to mammals. Endogenous retroviruses (RNA-based viruses), relics of ancient germ-cell infections, comprise 1% of the human genome.⁶¹ In fact, these viruses may have been involved in key events leading to the evolution of all placental mammals from egg laying-ancestors.⁶²

Consideration of the developmental and hereditary symbiosis leads to the conception of every eukaryote as a superorganism, a "symbiome" comprised of chromosomal genes, organellar genes, and often with other bacterial symbionts inside and outside the cell.⁶³ All plants and animals involve complex ecological communities of microbes. The symbiome functions as a unit of selection. The recognition of the "symbiome", the genomes within cells nucleus: mitochondria, chloroplasts, viral genomes, and of other microbes inside and outside the cell, entails dramatic alterations to neo-Darwinian theory and to our concept of the individual.

Today's neo-Darwinian synthesis holds gene mutations and recombination as providing the fuel for evolution by natural selection. But the evolutionary edifice that classical evolutionists constructed was a sterile conception without bacteria. Still today when there is ample evidence to support that view that symbiosis is widespread and plays a major role in evolutionary change, examples of microbial symbiosis are still seen as "exceptions" as "curiosities" by classical microbial evolutionists. Thus, Stephen Jay Gould regarded the symbiotic origin of mitochondria and chloroplasts as "entering the quirky and incidental side" of evolution.⁶⁴

Based on theoretical assumptions about the evolution of cooperation leading neo-Darwinian theorists have also insisted that the inheritance of acquired bacteria is a rare exceptional phenomenon in plants and animals. Despite evidence to the contrary, John Maynard Smith and Eors Szathmary asserted in 1999 that "transmission of symbionts through the host egg is unusual."⁶⁵

Distinguished population geneticist Theodosius Dobzhansky aptly asserted in 1973 that "Nothing in biology makes sense except in the light of evolution."⁶⁶ He did so to emphasize the importance of evolutionary thinking to non-evolutionists, and to those biological researchers who simply do not consider it as much as they ought to. Here I emphasize that "Nothing in evolution makes sense except in the light of bacteria" and that "Nothing in evolution makes sense except in the light of symbiosis."

It's a Microbial Earth

Ostensibly, the Darwinian evolutionary synthesis displaced humans at the centre of the earth; yet biologists certainly have not displaced them at the centre of evolutionary thinking. We can still hear intimations of an evolutionary hierarchy, almost like a great chain of being with humans at the top. Even the most devote Darwinian biologists speak of "higher" and "lower" plants and animals. Humans and other animals are "higher," bacteria the lowest of organisms. Nonetheless, this is, in reality, not merely our own eukaryotic chauvinism. Indeed, whole books on evolutionary biology are written in which the word "bacteria" is virtually absent. Part of this absence is owing to our anthropocentric world view of bacteria as "germs," and as the enemy of humans. (We can also still hear ecologists speak of the role of parasites in regulating populations, in the teleological style of the natural theologian viewing a common good in nature's plan. This non-Darwinian way of seeing, this convergence with the natural theologian of old is actually a way of seeing for environmental preservation.) Our definition of ourselves, our relations with nature and to each other is a question of politics. Our anthropocentrism is understandable.

Yet, the earth is essentially a microbial planet. Nature has no special partiality for humans. And bacteria, these so-called "lower organisms" are not nearly as simple as they might seem. They can pack more biochemical diversity into a couple of cubic micrometers than humans can in a couple of

kilograms of liver, kidneys and other offal. They, of course, do not need hearts and lungs as they breathe by diffusion. They developed unparalleled propellers and swim at speeds exceeding a thousand lengths a minute. To fly, they need no wings muscle or feather, just get blown effortlessly and can get anywhere. And bacteria can reproduce at rates many orders of magnitude higher than humans. They evolve much faster. The trick to all this is not just miniaturization. Bacteria have mechanisms of heredity and of evolutionary change unconsidered by the architects of the Darwinian synthesis, necessarily so, because their secrets had not yet been revealed.

By the end of the nineteenth century, bacteria were known to be omnipresent, in air, soil and water; they developed in masses where decomposition, corruption, fermentation or putrefaction was present. Bacteriologists in pathology, agriculture and industry were admired for their detailed studies of the physiological properties of bacteria, and for ascertaining their great importance for life and disease, for their refined methods of culture, preparation, staining, and microscopic observations. Despite these brilliant results, until a few decades ago, only a few specialists even attempted to understand bacteria in light of evolution. And to the public microbes are virtually unknown except in contexts of disease and rot, or bread, cheese, beer, wine, and bio-warfare.

Classical evolutionary biology (the evolution of plants and animals over the past 560 million years) did not consider 85% of evolutionary time on earth: the evolution of bacteria (*sensu lato*), now held by some estimates to be the largest biomass on earth,⁶⁷ with the greatest biochemical diversity on earth. Nor did it consider how protists, fungi, plants, and animals, emerged from them. The authors of the neo-Darwinian synthesis, of course, assumed that plants and animals evolved from "lower," "primitive" that bacteria were supposed to be - ancient organisms sort of frozen in evolutionary time. Bacteria lacked any coherent definition, and they remained outside any general evolutionary or phylogenetic framework.

It was not until the decade after the Second World War that the diverse mechanisms of bacterial heredity were discerned. Bacteria were shown to have genes, like other organisms. But still one could not construct genealogies for bacteria because they lacked the kinds of complex morphological traits for doing comparative morphology - the way in which the genealogies of plants and animals were reconstructed. It was not until the 1970s and 1980s with the birth of the field of "molecular evolution," that

bacterial phylogeny could be systematically investigated. Bacterial genealogical classification was to be based on a comparative molecular morphology, led by the research of Carl Woese and his collaborators.⁶⁸ Today microbial evolutionists show deep branching in the evolutionary tree. Humans are very recent additions to what is fundamentally a microbial world.

Certainly we humans and other animals are far more elaborate morphologically, but those who work on the evolution and phylogeny of bacteria suggested that they possessed greater biological diversity than plants and animals combined.⁶⁹ Whereas we humans other animals and plants developed complex structural modifications to obtain food materials of certain limited kinds, the bacteria have maintained themselves by acquiring the power of assimilating simple and abundant foods of various sorts. Evolution had developed gross structure in one case without altering metabolism, and it had produced diverse metabolism in the other case without altering gross structure. Thus as one leading bacteriologist put it 90 years ago, "There is as wide a difference in metabolism between pneumococci and the nitrifying bacteria as there is in structure between a liverwort and an oak."⁷⁰

Within one insect species one can find hundreds or thousands of distinct microbial "species."⁷¹ A handful of soil contains thousand of millions of organisms, so many different types that accurate numbers remained unknown. Most life in the ocean is microbial. Bacteria can live in an incredible variety of conditions from well below freezing to above the normal boiling temperature of water. Extreme halophiles thrive in brines so saturated that they would pickle other life. Other microbes live in the deep border of the trench at the bottom of the Red Sea in hot saline loaded with toxic heavy metal ions. They are also found growing in oil deposits, deep underground. Microbial evolutionists have only scratched the surface of microbial diversity. The entire surface of this planet down to a depth of at least several kilometers may be a habitat for microbes.

Bringing bacteria into the evolutionary framework of biology over the past twenty-five years has entailed vital changes to evolutionary theory. In addition to the importance of symbiosis in evolution, microbial evolutionists have brought to the fore evolutionary mechanisms within the bacteria whose scope and significance they had underestimated: gene transfer between phylogenetic groups. Bacteria possess several mechanisms for transmitting genes between unrelated groups -through conjugation, viral transduction, and transformations.

Conjugation: In addition to a main circular “chromosome,” bacteria, possessed smaller rings of genes, named “plasmids.” In bacterial conjugation, genetic material of the “male” plasmids, (and sometimes small to large parts of the main chromosome), is transferred to the “female” recipient, and some genes may recombine with the female’s chromosome.

Transformations: Certain kinds of bacteria can absorb and incorporate into their own chromosome, the DNA released by dead bacteria.

Transduction: Viruses or bacteriophage can act as vehicles to transfer genes between bacteria.⁷²

Thus, a bacterium of one type may acquire many genes from completely unrelated organisms.⁷³

Recognition of the pervasiveness of gene transfer between different kinds of bacteria entailed modifications to two seminal views about microbial evolution and the course of early evolution: their tree-like branching genealogies, and its hierarchical nature. Instead of the branching genealogical tree that Darwin imagined for plants and animals, the evolution of the bacteria is reticulated. Gene transfers between taxa make it resemble more a web than a tree.⁷⁴ Horizontal gene transfer blurs the boundaries between “species.” The ease with which genes are interchanged among bacteria has led many microbiologists to suggest that the biological species concept does not apply.⁷⁵ Only a tiny fraction of bacteria can be cultured. And part of the reason is that bacteria of one kind provide the conditions for another; there is a sort of division of labour, like the cells in our body. Because of this, and rapid gene transfer across the phylogenetic spectrum, some have suggested further that the entire bacterial world should be thought of as a super-organism.⁷⁶

Concluding remarks

The most well-known evolutionist before Darwin, Jean-Baptiste Lamarck considered humans to be the highest and most perfect form of organization, but he did not consider them to be the endpoint of evolution. He recognized that humans possessed some of the worst qualities as well as some of the best. In 1817 he wrote: “One would say that [man] is destined to exterminate himself after having rendered the globe uninhabitable.”⁷⁷ Darwin had

a different perspective. In his private correspondence, he wrote that “man in the distant future will be a far more perfect creature than he now is,” and that natural selection, driven by the struggle for existence between races, would continue to play a major role in human evolution.⁷⁸ Darwin interpreted the Crusades in these terms. As he commented to his correspondent in 1881:

Lastly, I could show fight on natural selection having done and doing more for the progress of civilisation than you seem inclined to admit. Remember what risks nations of Europe ran, not so many centuries ago, of being overwhelmed by the Turks, and how ridiculous such an idea now is! The more civilized so-called Caucasian races have beaten the Turkish hollow in the struggle for existence. Looking to the world at no very distant date, what an endless number of the lower races will have been eliminated by the higher civilized races throughout the world.⁷⁹

Darwin’s views were rooted in the erroneous concept of race of his time. Like the eugenicists who followed him early in the twentieth century, he failed to recognize the sizeable role of the environment, culture and education in establishing human characteristics. Moreover, geneticists later showed that all races are populations with mixtures of many different groups, and that the genetic diversity between individuals is far greater than it is between races. The differences between races are literally skin deep.⁸⁰

Evolutionary change is not simply a matter of conflict, struggle, and divergence. It is also a process of integration, forming mergers. Diversity and mixing have also been creative forces in our larger human social history. One might conjecture that the technological transfer of human populations around the globe today has speeded up human evolution. Gene transfer is rampant between individual human genomes and occurs with every genetic generation. There is extreme reticulation between individual human genomes. We can at least hope that Lamarck will also be proven wrong.

Notes and References:

1. Arthur O. Lovejoy, *The Great Chain of Being. A Study of the History of an Idea* (Cambridge, Mass: Harvard University Press, 1936).
2. Charles Darwin, *On the Origin of Species*, with an introduction by Ernst Mayr, facsimile edition of 1859 (Cambridge: Harvard University Press, 1964), 420.
3. *Ibid.*, 490.
4. Adrian Desmond, *Huxley: From Devil's Disciple to Evolution's High Priest* (Reading Mass: Perseus Books, 1994).
5. Charles Darwin to Mr. J. Fordyce 1879 in Darwin, ed., *The Autobiography of Charles Darwin*, 60-66, 66.
6. Charles Darwin, *On The Origin of Species*. Facsimile ed., with an introduction by Ernst Mayr (Cambridge Mass: Harvard University Press, 1964), 488.
7. Charles Darwin, *The Descent of Man* (London: John Murray, 1971).
8. Thomas H. Huxley, *Man's Place in Nature*, (Ann Arbor: The University of Michigan Press, 1959).
9. Huxley, *Man's Place in Nature*, 71.
10. There is a great body of literature on "Social Darwinism." See for example, John Greene, "Biology and Social Theory in the Nineteenth Century," in Marshall Clagett ed., *Critical Problems in the History of Science* (Madison: University of Wisconsin Press, 1962), 416-446. Richard Hofstadter, *Social Darwinism in American Thought*, Rev. ed., (Boston: Beacon Press, 1955). Greta Jones, *Social Darwinism in English Thought* (London: Harvester, 1980). Robert Young, *Darwin's Metaphor. Nature's Place in Victorian Culture* (Cambridge: Cambridge University Press, 1985). *Idem.*, "Darwinism Is Social" in David Kohn, ed., *The Darwinian Heritage* (Princeton: Princeton University Press, 1985), 609-38. For a critique of Young's approach see, Ingemar Bohlin, "Robert M. Young and Darwin Historiography," *Social Studies of Science* 21 (1991): 597-648. Jim Moore, "Socializing Darwinism: Historiography and the Fortunes of a Phrase," in Les Levidow ed., *Science as Politics* (London: Free Association Books, 1986), 38-75.
11. Robert Young, *Darwin's Metaphor* (Cambridge: Cambridge University Press, 1985), 3. See also, R.C. Lewontin, "The Concept of Evolution," in D.L. Sills ed., *International Encyclopedia of Social Science* vol 5 (New York: Macmillan, Fress Press, 1968), 2002-10. *Idem.*, *The Genetic Basis of Evolutionary Change* (New York: Columbia University Press), 1974.
12. Richard Dawkins, *The Selfish Gene*, New Edition (Oxford: Oxford University Press, 1989), 19-20.
13. Dawkins, *The Extended Phenotype*, p.237. See also Garrett Hardin, "The Tragedy of the Commons," *Science* 1968: 1243-48.

14. Reg Morrison, *The Spirit of the Gene: Humanity's Proud Illusion and the Laws of Nature*. (Ithaca: Cornell University Press, 1999).
15. *Ibid.*, 173-74.
16. There are a vast number of books and articles on the sociobiology debate. I will mention here, Arthur Caplan, ed., *The Sociobiology Debate* (New York: Harper and Row, 1978). Joe Crocker, "Sociobiology: The Capitalist Synthesis," *Radical Science Journal* 13 (1983):55-71. W.R. Albury, "The Politics of Truth: A Social Interpretation of Scientific Knowledge, With an Application to the Case of Sociobiology," in Michael Ruse ed., *Nature Animated*, Dordrecht: D. Reidel, 1983), 115-129. S. Rose, L.J. Kamin and R.C. Lewontin, *Not in Our Genes: Biology and Human Nature* (Harmondsworth: Penguin, 1984). Philip Kitcher, *Vaulting Ambition. Sociobiology and the Quest for Human Nature* (Cambridge: The MIT Press, 1987). Ullica Segerstråle, *Defenders of the Truth. The Battle for Science in the Sociobiology Debate and Beyond* (New York: Oxford University Press, 2000).
17. Lewontin, *Biology as Ideology*, 67.
18. See Ernst Mayr., 'The Objects of Selection', *Proceedings of the National Academy of Sciences* 94 (1997): 2091-2094.
19. This panselctionism was the main target of Gould and Lewontin's influential paper of 1978, "The Spandrels of San Marco and the Panglossian Paradigm: a Critique of the Adaptationist Program." Stephen Gould and Richard Lewontin, "The Spandrels of San Marco and the Panglossian Paradigm: a Critique of the Adaptationist Program" *Proc. R. Soc. London B Biol. Sci.* 205 (1978): 581-598.
20. On insect flight see: J.H. Marden, and M.G. Kramer, "Plecopteran surface-skimming and insect flight evolution - reply." *Science* 270, (1995) 1685. *Idem.*, "Locomotor performance of insects with rudimentary wings," *Nature* 377 (1995):332-334. J.H. Marden, M.R. Wolf, and K.E. Weber. 1997. "Aerial performance of *Drosophila melanogaster* from populations selected for upwind flight ability," *Journal of Experimental Biology* 200, 2747-2755. M.G. Kramer and J.H. Marden, "Almost Airborne," *Nature* 385 (1997): 403-404.
21. Voltaire, *Candide or Optimism*, trans. John Butt (London: Penguin Books, 1947), 20.
22. Dawkins wrote, "If an individual dies in order to save ten close relatives, one copy of the kin-altruism gene may be lost, but a larger number of copies of the same gene is saved." *The Selfish Gene*, 90.
23. S. J. Gould, "Sociobiology: the Art of Storytelling," *New Scientist* 80 (1978): 530-533.
24. See Elizabeth Pennisi, "Finally, the Book of Life and Instructions for Navigating it," *Science* 288 (2000): 2304-2307.
25. See Alex Mauron, "Is the Genome the Secular Equivalent of the Soul?" *Science* 291 (2001):831-832.

26. See, Carl F. Canor, ed., *Are Genes Us? The Social Consequences of the New Genetics* (New Jersey: Rutgers University Press, 1994). Daniel Kevles and Leroy Hood eds., *The Code of Codes. Scientific and Social issues in the Human Genome Project* (Cambridge: Harvard University Press, 1992). Tom Wilkie, *Perilous Knowledge. The Human Genome Project and its Implications* (Berkeley: University of California Press, 1993). Timothy F. Murphy and Marc A. Lappé, eds., *Justice and the Human Genome Project* (Berkeley: University of California Press, 1994). Robert Cook-Deegan, *The Gene Wars. Science, Politics, and the Human Genome* (New York: W. W. Norton, 1994). Lois Wingerson, *Unnatural Selection. The Promise and the Power of Human Gene Research* (New York: Bantam Books, 1998). Richard Lewontin, *It Ain't necessarily So. The Dream of the Human Genome and Other Illusions* (New York; New York Review of Books, Inc. 2000). Phillip R. Sloan ed., *Controlling Our Destinies: Historical, Philosophical, Ethical, and Theological Perspectives on the Human genome Project* (Notre Dame: University of Notre Dame Press. 2000).

27. See Dean Hamer and Peter Copeland, *Living with Our Genes* (New York: Anchor Books, 1998). Richard Lewontin, *The Triple Helix. Gene Organism and Environment* (Cambridge: Harvard University Press, 2000).

28. See for example, the excellent study by Dorothy Nelkin and Susan Lindee, *The DNA Mystique. The Gene as a Cultural Icon* (New York: W. H. Freeman and Co., 1995).

29. Matt Ridley, *Genome*, (New York: Harpercollins, 2000), 1.

30. For discussion of such issues see, Jan Sapp, *Genesis. The Evolution of Biology* New York: Oxford University Press, 2003.

31. See David Adam, "Draft Human Genome Sequence Published," *Nature* news Feb. 12, 2001; Henry Gee, "A Journey into the Genome: What's There," *Nature* news Feb.12., 2001. International Human Genome Sequencing Consortium, "Initial Sequencing and Analysis of the Human genome," *Nature* 409 (2001):860-920. J. Craig Venter et al., "The Sequence of the Human Genome," *Science* 291 (2001):1304-1345.

32. Ju Yu et al. "A Draft Sequence of the Rice Genome (*Oryza sativa* L. Ssp. Indica)," *Science* 296 (2002):79-100.

33. See Lynda Hurst, "Genome just a start for maverick scientist," *The Toronto Star*, April 24, 2002.

34. See Sharp, "Split Genes and RNA Splicing."

35. For a discussion of these issues see, Phillip A. Sharp, "Split Genes and RNA Splicing," Nobel Lecture, *Cell* 77 (1994): 805-815. For an early general review and discussion of the significance of alternative splicing see, B. Lewin, "Alternatives for Splicing: Recognizing the ends of Introns," *Cell*, 22 (1980): 324-326.

36. Athena Andreadis, M.E. Gallego, B. Nadal-Ginard, "Generation of Protein Isoform Diversity by Alternative Splicing: Mechanistic and Biological Implications,"

Annual Review of Cell Biology 3 (1987): 207-242. See also Bruce Alberts et al., *Molecular Biology of the Cell* 2nd Edition (New York: Garland,1989), 536, 588.

37. Jan Sapp, *Genesis The Evolution of Biology*, New York: Oxford University Press, 2003

38. See A. Andreadis M.E. Gallego, B. Nadal-Ginard, "Generation of Protein Isoform Diversity by Alternative Splicing: Mechanistic and Biological Implications," *Annual Review of Cell Biology* 3 (1987): 207-242. See also, Bruce Alberts et al., *Molecular Biology of the Cell* 2nd Edition, (New York: Garland,1989),536, 588.

39. See Venter, "The Sequence of the Human Genome," 1346. International Human Genome Sequencing Consortium, "Initial Sequencing and Analysis of the Human Genome," 898, 901.

40. See Michael E. Zwick, David J. Cutler and Aravinda Chakravarti, "Patterns of Genetic Variation in Mendelian and Complex Traits," *Annu. Rev. Genomics Hum. Genet.* 1 (2000): 387-407.

41. Sharp, "Split Genes and RNA Splicing."

42. See Tom Bethell, "A Map to Nowhere" *The American Spectator*, April 2001, 51-56.

43. See Sharp, "Split Genes and RNA Splicing," 807-808. On the history of the gene concept see P. Portin, "The Concept of the Gene - Short History and Present Status." *Quarterly Review of Biology* 68 (1993):173 - 223. Idem., "Historical Development of the Concept of the Gene," *Journal of Medicine and Philosophy* 27 (2002): 257-286. Peter Beurton, Raphael Falk and Hans-Jörg Rheinberger eds., *The Concept of the Gene in Development and Evolution: Historical and Epistemological Perspectives* (Cambridge: Cambridge University Press, 2000). Evelyn Fox Keller, *The Century of the Gene* (Cambridge: Harvard University Press, 2000).

44. Raphael Falk, "The Gene - A Concept in Tension," in Buerton, Falk and Rheinberger eds., *The Concept of the Gene in Development and Evolution*, 317-348, 340.

45. See Theodor Rosebury, *Life on Man* (London: Paladin, 1969). Frederic Bushman, *Lateral DNA Transfer. Mechanisms and Consequences* (New York: Cold Spring Harbor Laboratory Press, 2002).

46. See L.V. Hooper L. Bry, P.G. Falk, and J.I. Gordon "Host-microbial Symbiosis in the Mammalian Intestine; Exploring an Internal Ecosystem," *BioEssays* 20 (1998):336-343. L. V. Hooper, M. H. Wong, A. T. Lennart Hansson, P.G. Falk, and J. I. Gordon, "Molecular Analysis of Commensal Host-Microbial Relationships in the Intestine," *Science* 291 (2001): 881-884.

47. These bacteria convert nitrates to nitrites which, in the acid environment of our stomachs, produce the pathogen-fighting chemical nitric oxide. See Elizabeth Pennisi, "Integrating the Many Aspects of Biology," *Science* 287 (2000):419-421.

48. R.D. Berg, "Probiotics, Prebiotics or Conbiotics?" *Trends in Microbiology* 6 (1998):89.
49. Joshua Lederberg, "Beyond the Genome," *Brooklyn Law Review* 67 (2001):7-12.
50. Sapp, *Evolution by Association*. Sapp, *Genesis*.
51. See for example, W. Schwemmler, *Symbiogenesis: A Macro-Mechanism of Evolution. Progress toward a Unified Theory of Evolution* (Berlin: Walter de Gruyter, 1989). Mary Beth Saffo. "Symbiosis in Evolution," in E.C. Dudley, ed. *The Unity of Evolutionary Biology. Proc. of the Fourth Int. Congr. of Systematics and Evolutionary Biology* (Portland Or.: Dioscorides Press, 1991), 674-680,. See also essays in Lynn Margulis and René Fester eds., *Symbiosis as a Source of evolutionary innovation, Speciation and Morphogenesis* (Cambridge, Mass: MIT Press, 1991). Sapp, *Evolution by Association*. Lynn Margulis and Dorion Sagan, *Acquiring Genomes. A Theory of the Origins of Species*. (New York: Basic Books, 2002).
52. See, John Lear, *Recombinant DNA: The Untold Story* (New York: Crown, 1978). Ted Howard and Jeremy Rifkin, *Who Should Play God?* (New York: Dell, 1977). June Good field, *Playing God* (New York: Random House, 1977). Nicholas Wade, *The Ultimate Experiment: Man-Made Evolution* (New York: Walker and Co., 1977). Sheldon Krimsky, *Genetic Alchemy. The Social History of the Recombinant DNA Controversy* (Cambridge: the MIT Press, 1982). Raymond A. Zilinskas and Burke K. Zimmerman, eds., *The Gene-splicing wars: Reflections on the Recombinant DNA Controversy* (New York: Macmillan), 1986. See also, Philip Kitcher, *The Lives to Come, The Genetic Revolution and Human Possibilities* (New York: Touchstone, 1996). Tom Wilkie, *Perilous Knowledge* (Berkeley, The University of California Press, 1993). Lois Wingerson, *Unnatural Selection* (New York: Bantam Books, 1998).
53. As an illustration of how the null hypothesis over horizontal gene transfer has changed, in 2001, human genome researchers published suggestive, though controversial, evidence that humans have acquired hundred of genes directly from bacteria. See Nicholas Wade, "Link Between Human Genes and Bacteria is Hotly Debated," *New York Times*, May 18, 2001. See Steven L. Salzberg, Owen White, Jeremy Peterson, and Jonathan A. Eisen "Microbial Genes in the Human Genome: Lateral Transfer or Gene Loss?" *Science* 292 (2001): 1903-1906. Michael J. Stanhope, et al., "Phylogenetic Analysis do Not Support Horizontal Gene transfers from Bacteria to Vertebrates," *Nature* 411 (2001): 940-944.
54. See Jan Sapp, *Genesis: The Evolution of Biology* (New York: Oxford University Press, 2003).
55. J. Sapp, "Paul Buchner and Hereditary Symbiosis in Insects," *International Journal of Microbiology*, September, 5 (2002): 145-160.
56. See Angela Douglas, "Nutritional Interactions in Insect-Microbial Symbioses: Aphids and their symbiotic bacteria *Buchnera*," *Annual Review of Entomology* 43 (1998): 17-37.

57. See Paul Buchner, *Endosymbiosis of Animals with Plant Microorganisms*. Translated by Bertha Mueller (New York: Interscience, 1965).
58. J. H. Werren,, "Biology of *Wolbachia*," *Annual Review of Entomology* 42 (1997): 587-609. See also James Higgins ad Abdu F. Azad, "Use of Polymerase Chain Reaction to Detect Bacteria in Arthropods: A review," *Journal of Medical Entomology* 32 (1995):13-22. Wenseelers, et al., "Widespread Occurrence of the Micro-organism *Wolbachia* in Ants', *Proceedings of the Royal Society of London B* 265 (1998): 1447-1452. J.H. Werren and D. Windsor, "*Wolbachia* Infection Frequencies in Insects: Evidence of A Global Equilibrium," *Proceedings of the Royal Society of London R* 267 (2000): 1977-1995.
59. See C. Zimmer, "*Wolbachia*: A Tale of Sex and Survival," *Science* 292 (2001): 1093-1096.
60. H. Abdelaziz, et al., "Four Intracellular Genomes Direct Weevil Biology: Nuclear, Mitochondrial, principal Endosymbiont, and *Wolbachia*," *Proceedings of the National Academy of Sciences USA* 96 (1999):6814-6819.
61. See Roswitha Löwer, Johannes Löwer and Reinherd Kurth, "The Viruses in all of us: Characteristics and Biological Significance of Human Endogenous Retrovirus Sequences," *Proc. Natl. Acad. Sci. USA* 93 (1999): 5177-5184.
62. J. Robin Harris, "Placental Endogenous Retrovirus (ERV): Structural, functional, and Evolutionary Significance," *BioEssays* 20 (1998):307-316.
63. See also Sapp, *Genesis*, 2003. Joshua Lederberg coined the term microbiome, "to signify the ecological community of commensal, symbiotic, and pathogenic microorganisms that literally share our body space and have been all but ignored as determinants of health and disease. " J. Lederberg & Alexa McCray," Ome Sweet 'Omics: A Genealogical treasure of words," *The Scientist*, 15 (February 4, 2001):8.
64. S. Jay Gould, *Wonderful Life. The Burgess Shale and the Nature of History* (London: Hutchison Radius, 1989), 310. Symbiosis is not mentioned at all, and bacteria are allotted 3 pages of 1200, in Stephen Jay Gould's treatise, *The Structure of Evolutionary Thought* (Cambridge Mass: Harvard University Press, 2002).
65. J. Maynard Smith and E. Szathmáry, *The Origins of Life. From the Birth of Life to the Origin of Language* (New York: Oxford University Press 1999), 107. See also *Idem. The Great Transitions in Life* (New York: W.H. Freeman and Co. 1995), 195.
66. I.Theodosius Dobzhansky, "Nothing in Biology Makes Sense Except in the Light of Evolution," *The American Biology Teacher* 35 (1973): 125-129.
67. W. B. Whitman, D. C. Coleman and W. J. Wiebe, "Prokaryotes: The Unseen Majority," *Proceedings of the National Academy of Sciences USA* 95 (1998): 6578-6583.
68. See Jan Sapp, "The Bacterium's Place in Nature," in J. Sapp, ed., *Microbial Evolution. Concepts and Controversies*. New York: Oxford University Press, in press.

69. Olsen, G., Woese, C., "Lessons from an Archaeal Genome: What are we learning from *Methanococcus jannaschii*?" *Trends in Genetics* 12 (1996): 377-379.
70. Winslow, "The Characterization and Classification of Bacterial Types," 85.
71. N. Pace, "A Molecular View of Microbial Diversity and the Biosphere," *Science* 276 (1997): 734-740, 734.
72. J. Lederberg, "Cell Genetics and Hereditary Symbiosis," *Physiological reviews* 32 (1952):403-30. Idem., "Genetic Transduction," *American Scientist* 44 (1956): 264-280.
73. For an excellent review of the biology of horizontal gene transfer see Frederic Bushman, *Lateral DNA Transfer. Mechanisms and Consequences* (New York: Cold Spring Harbor Laboratory Press, 2002).
74. See Doolittle, "Phylogenetic Classification."
75. See Howard Ochman, Jeffery G. Lawrence and Eduardo Grolsman, "Lateral Gene transfer and the Nature of Bacterial Innovation," *Nature* 405 (2000):299-304. Jonathan Eisen, "Horizontal gene transfer Among Microbial Genomes: A New Insight from Complete Genome Analysis," *Current Opinion in Genetics and Development* 10 (2000): 606-611.
76. See S. Sonea and P. Panisset, *The New Bacteriology* (Boston: Jones and Bartlett, 1983). S. Sonea and L.G. Mathieu, *Prokaryotology*. (Les Presses de l Université de Montréal, 2000).
77. J. B. Lamarck, *Zoological Philosophy. An Exposition with regard to the Natural History of Animals*; (1809) Translated by Hugh Elliot, with a forward by Richard Burkhart (Chicago: University of Chicago Press, 1984),ppp. xxxiii.
78. F. Darwin ed., *The Autobiography of Charles Darwin*, 65.
79. Charles Darwin letter to W. Graham, 3 July, 1881, in F. Darwin ed., *The Autobiography of Charles Darwin*, 69.
80. Richard Lewontin analyzed the diversity of blood types within populations and showed that 85% of the variation was within human populations, while only 15 percent was between populations. See Richard C. Lewontin, "The Apportionment of Human Diversity," *Evolutionary Biology* 6 (1972): 381-98. Idem., *Human Diversity* (San Francisco: Scientific American Books, 1982). See also, Joshua Lederberg, "The Genetics of Human Nature," *Social Research* 40 (1973): 375-406. Luigi Luca Cavalli-Storza, *Genes, Peoples, and Languages* (New York: North Point Press, 2000).