Epigenetics vs. Genetic Determinism

An Interview with Stuart Newman

Casey Walker: As a cellular biologist, where do you see poor assumptions and bad theory playing themselves out in biogenetic engineering?

Stuart Newman: It begins with the false idea that organisms can be designed to specification, or corrected by popping in new genes and popping out bad genes. We see these assumptions in agriculture with genetically engineered foods, and with practices such as inserting naturally occurring insecticide proteins into crop plants like corn. There is a prevailing and, in my view, incorrect idea that genes are modular entities with a one-to-one correspondence between a function and a gene. My particular interest is in how these ideas are being played out in human biology, where we see the same kind of genetic reductionism justifying attempts to assign genes to complex conditions such as schizophrenia, intelligence, homosexuality, and so forth. Definition of problems in genetic terms obviously leads to calls for genetic solutions with profound consequences for human beings and evolution.

Although it's unquestionable that every complex biological condition has a genetic component to it, the mediation that occurs between the genetic component and the actual behavior or feature is typically quite complex and should militate against taking the reductionist approach. Frequently, a gene in one context will influence a condition in one way and in a different context will influence the condition in a completely different way. There's simply very bad theory behind a lot of the genetic interventions now being proposed. In particular, bad theory (tied to commercial interest) is at the root of proposals for human germline modification, which would take a human embryo on the path to developing one condition or another, perhaps a disease, and modify its genes.

Is it misleading to perceive genetic expression and environmental influence as two discrete processes?

Yes. There's a genetic component to an organism's susceptibility to environmental effects and there's an environmental component to its expression of genetic effects. Thus, there's a composite of interpenetrating genetic and environmental processes that give rise to every organism during development. Another very common misperception comes with the conclusion that anything congenital–inborn–is inherited from the parents' genes. There are many studies currently attempting to tie personality traits such as shyness or aggression to genes. While people do recognize that various traits seen in their children were there from the very start, they need to also recognize and understand that the developmental processes of that child were far more complex than a playing out of its inherited genes. There are infinitely complex processes during development that make each outcome unique. Features in a newborn that are undeniably congenital and could even be said to be "hardwired" into the biology of that person may have very little to do with either parent. Thus, to say something is "congenital" does not mean it can be deconstructed and attributed to inheritance from one or the other parent.

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Will you describe those processes that influence various outcomes during development of the human embryo?

At the start of development, the fertilized egg has all the nuclear genes contributed by its parents, and also the separate mitochondrial genes from the mother in the cytoplasm of the egg. The egg's cytoplasm also contains protein and RNA products of some of the mother's genes that are not part of her genetic contribution to the embryo. At first, the genes in the nucleus of this newly fertilized egg start to be activated and cause proteins to be made. But that's not the only thing that's going on. There's the mother's uterine environment that this organism is exposed to, and there is an "intrinsic plasticity" that allows the embryo to readjust and recover from perturbations or disturbances. For example, if you have a two-cell embryo and somehow the cells get detached from one another, each of those two cells–even though both were originally one-half of an individual–will go ahead and become a separate, complete individual. This of course is the basis of twinning. Mouse embryos at the two-cell stage can be separated and each of the cells will make an individual, even though under natural circumstances they wouldn't have done it. Through this kind of plasticity, a species-characteristic outcome is achieved even if it now takes the form of two organisms.

Something even more unusual can be done experimentally that may never or only rarely happen in natural circumstances, which is to take two embryos that are separate from each other and jumble the cells together. Again these cells will readjust their fates to create a complete individual. You can show this by taking organisms of two different strains, or two different species, and creating one single organism from them. You can make a chimera–which is what these combined embryos are called–between a sheep and a goat (a "geep"). Of course, that would never happen in nature, yet we do get a composite individual with all the normal parts.

Which implies a kind of strategy or will within embryonic cells?
It's a subject of major, scientific debate as to what it implies. Some say that throughout our evolution embryos and organisms have been subjected to so many different stresses and strains and aberrant environments and strange conditions that we have within us a completely hardwired set of programs to get us out of all of these things that might happen. This notion has been put forward by some prominent developmental biologists recently and called "adaptability." They say this developmental plasticity is a very sophisticated product of our evolutionary history, and is dependent upon highly evolved genetic circuits and programs.

Advocates of genetic engineering claim that it is no different from what evolution has done, and that it is in fact a new form of evolution. But genetically engineered crops are not analogous to products of normal evolution. If epigenetic causation is the motor of evolution as I have proposed, and genes play a subordinate, consolidating role, then going at the properties of an organism by manipulating its genes is not even really "engineering." It is the hit-or-miss production of potentially useful monstrosities.

That's not the view I take. I see plasticity, or the ability to readjust in the face of environmental change and to take on characteristic forms despite all the vicissitudes of the developmental process, as a property intrinsic to the materials that make up organisms. An analogy may help here. If you look at rain, you'll see that every raindrop falling through the air has the same shape. Why is that? Not because a raindrop has genes to develop its shape, but because it's a piece of a particular kind of matter, a drop of water being subjected to certain external, physical processes. If you take a still body of water and agitate it, you will always make waves; if you swirl it, you will always make vortices. Here too, a particular material will do a certain set of stereotypical or "generic" things because of its composition and the forces to which it is susceptible. There are many more sophisticated properties that certain materials can exhibit–even if they're not alive–that support this view. There's a whole class of materials called "excitable media" that are studied by physicists and chemists. These are things that will give you back more than you put into them because they contain stored energy and have a stored ability to react chemically. For example, chemical reactions of diffusing molecules can spontaneously produce stripes or spots or spirals of chemical substance arranged across a spatial domain. Since this occurs with nonliving materials, we know there's something characteristic about excitable material itself that is not simply the result of a list of ingredients (which is what the genes provide). Instead, the composite materials formed from those ingredients will exhibit certain generic physical behaviors.

Now, embryos are excitable media. They inevitably do certain things because of their physical and chemical properties. This opens up a whole new set of causalities in the formation of an organism. It's not simply tracking the playing out of genes, but, rather, recognizing that there are physical and chemical properties that arise as the products of genes interact with each other within cellular and multicellular contexts that also contain nongenetic substances–water, ions, and so forth.

Is there a threshold, a critical mass of cells, where an embryo becomes an "excitable medium"?

The excitability is there from the start because each individual cell is excitable. It's metabolizing, it's exchanging matter and energy with its environment. But individual cells have a limit as to how differentiated each can get. Even though a single cell has many substances in it and these substances may be produced in one part of the cell and not the other, there will be a rapid mixing and homogeneity will generally prevail because the cell is so small. However, with a cluster of cells, because it is larger, something may occur or be produced at one end and not at the other, and create the gradients or inhomogeneities which provide the basis for cells to differentiate and take on distinct roles. Increased size brings several new physical factors into play that affect cellular development. In addition to the role of diffusion just described, surface tension begins to play a role in embryo shape and tissue boundary formation. This is another factor which is not relevant at the scale of the individual cell.

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Now, if it is the case that in embryogenesis of a contemporary organism these physical processes have an importance that is neglected by concentrating solely on genetics, I will also tell you that evolution has also utilized the outcomes of those physical processes. In certain cases, the outcomes were adaptive–they led to organisms that were functionally adequate in certain environments–and those outcomes were consolidated by additional processes, often genetic, that built upon and stabilized them. If a physical process led to an outcome that worked in nature, then, after a great deal of evolution, we find there are ways of achieving that endpoint independent of the originating, physical process. This is important because evolution away from strict reliance on physical processes makes morphogenesis more robust and reliable.

When we look at modern organisms, we can see the imprint of these physical processes along with the genetic processes that support and reinforce them. The process of evolution opportunistically consolidates certain outcomes that may have originally arisen as a result of completely different causes. At the end of a long period of time, you have many parallel processes directed toward the same endpoint. In short, the modern organism which the embryo develops into is a very, very sophisticated structure that makes use of genetic processes, physical processes, and genetic processes that have co-opted the outcomes of physical processes in ways that physics alone can't do.

If we look back at the raindrop analogy, we see that the raindrop has a head and a tail because of the physical medium it's falling through and the material it's made of. But you can imagine that if the raindrop had genes as well and those genes were subject to evolution, you might find that after a half billion years that particular shape wouldn't necessarily depend on the continuous falling through the air in order to be maintained. You might get other ways–genetic ways–of getting that shape to be established. It is also clear from this that structures may arise for physical reasons that are not *for* anything and later become consolidated by genetic circuitry. These features, which may be as profoundly part of an organism's identity as body cavities or segments, may ultimately have little or nothing to do with adaptation.

When you write of the conceptual gap occurring today in evolutionary theory, is this it?

Yes. If we go back in evolutionary history, before genetic integration and consolidation took place, the interactions between the material of the organism and the external world were very conditional, very context-dependent. Such interaction-dependent causation is called "epigenetic." With virtual certainty, those processes were very important in early evolution. As evolution progresses, the genes capture some of these outcomes and integrate them into the repertoire of the organism, so that what previously depended upon organism-environment interaction is internalized and part of an intrinsic program in the system.

Yet we commonly assume genes generate rather than support various physical features?

Exactly. Even if a feature becomes genetically prescribed, its origin was most typically in an interaction. We can look at the outcome, the end products of evolutionary processes, and appreciate the ways in which genes latched onto all sorts of things that originated through epigenetic mechanisms. However, if you try to understand the structure of the system by just looking at the genes, you will be terribly confused. Life forms did not arise from incremental pathways of small genetic changes. Instead, genes basically insinuated themselves into processes that genes themselves did not originate–a phenomenon ignored in the neo-Darwinian notion of the incrementally achieved "genetic program." In other words, genetic integration is a post hoc scaffold that stabilizes life forms, but is very different from a program. Looking at organisms this way allows us to appreciate the fact that there are aspects of our biology that have been consolidated by genetic evolution even though genetic evolution did not originate those aspects.

This becomes interesting when we look at humans and consider our biological repertoire. Even if certain aspects of our biology are completely settled–as in the case of the general form of our body–that doesn't mean other aspects are. Our brain's physical form results from relatively programmed morphogenetic processes during our development, and yet its cognitive potential remains subject to interactions throughout our lives. New thoughts are not dependent on remolding the brain's morphology, but depend upon connections, many of which are conditional-epigenetic. Our brains are not finished products of evolution. The topology of the neuronal connections in the brain is plastic–fluid in the metaphorical sense. The ideas and values we hold are based on social interactions and interactions with the outside world.

That's not to say that genetic evolution may not eventually consolidate some of these aspects as well. For example, some species of birds learn who their predators are because their parents will squawk when predators come by and they learn to recognize certain silhouettes as hostile. Other birds have an inborn propensity to react very strongly against certain silhouettes. In some lineages of organisms, certain things result mainly from epigenetic interaction and in other lineages they result mainly from genetically-based propensities. Now, if we want to interpret what's going on in a reasonable way, it seems as if interaction plays the originating role, and genetics only captures and consolidates the behaviors under certain evolutionary circumstances.

Does this imply that evolution consolidates a certain taken-for-grantedness, a genetic wiring for survival?

It depends on the social and ecological setting any lineage finds itself in. It may be that under certain evolutionary circumstances things in the experience of that lineage get consolidated into the genome, but it's important to note that consolidation also leads to rigidification. If certain nonhuman species have a hardwired set of behavioral capabilities, they have thereby lost the plasticity that human brains still retain. I would suggest that cognitive plasticity is really, in some sense, a primitive feature that never got rigidified in the human lineage. Although our bodies have become evolutionarily stereotyped, our cognition has not. We've retained the interactive capacity that is probably at the origin of all cognition and behavior, but we've made use of that "primitive" plasticity to a much deeper extent than other species.

Is higher plasticity true of sentient organisms in general?

Humans and dolphins seem to have retained this much more than other organisms, and there's novelty that comes into play with it as well. If primordial organisms indeed had brains that exhibited a lot of behavioral plasticity, they were also very small brains which weren't capable of very high levels of cognition. But if you simultaneously have a large brain and one which has retained behavioral plasticity, you are in very good shape for interacting with your environment in novel and productive ways. Thus our behavior, thoughts, and imagination all depend on organism-organism and organism-environment interaction.

I also must say that this is an area in which I think the evolutionary psychologists and sociobiologists draw incorrect conclusions. Many look at primate species that are supposedly "lower" than we are or more "primitive" evolutionarily–which I think are incorrect ideas–and say that because certain stereotypical behaviors are found in both primates and human beings, these behaviors must be deeply embedded in our genes. I think this is totally wrong. Many behaviors–aggression, territoriality, sexual roles–may arise from circumstances in particular social settings, and initially depend on those social settings for their perpetuation. They may work in allocating resources in a successful fashion under certain constrained conditions. Those circumstances may pertain to certain human societies in our history, as well as to chimpanzees and baboons and so on, yet it's very reasonably the case that whereas these conditional outcomes may have become genetically integrated, consolidated, and hardwired in certain species–rats, baboons–they may still remain dependent on circumstance for humans. Even if a genetically-fixed behavior in an ant or a rat looks like a behavior we see in people, it doesn't mean that it's associated with particular genes in a person. This is a common fallacy and, again, comes from not appreciating the role of epigenetics and plasticity in evolution.

Will you address the concept of the "intensification of uniqueness" as opposed to "open-ended production of difference" as another way of looking at evolution?

The standard view of how organisms have evolved, which is the Darwinian view, assumes a general correspondence between genetic change and phenotypic change. There's a kind of uniformitarianism embedded in Darwinism that says that the general progress or alteration of phenotype is correlated with the general rate of alteration of the genotype. If you take that point of view, organisms are always on their way to becoming something else, and any boundaries between species are incidental. In Darwinism there's a general propensity to think that species identities are transient, temporary distinctions. They look like natural groupings, but the boundaries are always blurry because there's always the possibility of moving outside that perimeter through successive genetic change.

From which transgenics follows easily?

That's right. Darwinists say the idea that species are discrete, separate entities with species boundaries that are not crossed naturally is a remnant of biblical creationist ideas. The point of view that I'm describing, which is based on epigenetic causality, says that at the time the major differences between organisms arose, they did so on the basis of epigenetic changes–what I've also been calling plasticity or conditional and interactive processes. A given genotype would have exhibited a range of phenotypes, depending on the circumstances. In other words, there was no necessary connection between what the genetic content of an organism is and what the organism looks like. Physical and epigenetic determination may have been so important at these early periods of evolution that if the temperature, salinity, or some other aspect of the environment was changed, you would have gotten a very different looking organism. Now, if the origin of organismal diversity was in epigenetic processes, and if genetic evolution acted upon those dramatically divergent forms and consolidated them under various conditions of life, then after vast amounts of time you would have organisms that were no longer malleable or interconvertible. They would become walled off from each other by the genetic consolidation that evolution produces. Over time then, organisms stop changing into other kinds of organisms; they're becoming more *themselves*. Their characteristics are becoming more and more integrated and intensified so that at the end of a long period of evolution the boundaries between species have become much sharper. This view basically turns neo-Darwinism on its head in its proposal that phenotypic change precedes the genetic evolution that consolidates it. This is possible because most phenotypic innovation results from epigenetic processes. These processes can be mobilized by either environmental alteration or genetic mutation, but any new character that results will be subject to a more gradual cooptation by subsequent genetic evolution. This implies, contrary to neo-Darwinism, that most genetic change doesn't play an innovating role, it plays an integrating and stabilizing role. If you go back to the earliest history of organisms, I think it's inescapable that there was much less genetic integration, much less resistance to perturbation, and you had organismal forms that were malleable and polymorphic, because phenotypes were more dependent upon circumstance.

Such organisms differed from modern ones–their capacity to undergo phenotypic change in response to altered conditions having been virtually Lamarckian. After time, with genetic consolidation, organisms evolved into the Darwinian entities that populate the contemporary biosphere. However, the high degree of genetic integration means that the period of large-scale evolutionary change is over–Darwinian mechanisms of small phenotypic alterations due to small genetic changes will never result in a new genus, class, or phylum.

Along these lines I appreciated the analogy, in your chapter "Carnal Boundaries," that the organic possibilities of life are as distinct as the elements found on the periodic table.

Right. The periodic table displays the 110 or so stable "types" (elements) that are possible given the physics of the fundamental particles involved. This is all you can get, regardless of how much time elapses. I would suggest that in an analogous fashion, the pertinent physical and other epigenetic process acting upon aggregates of living cells can

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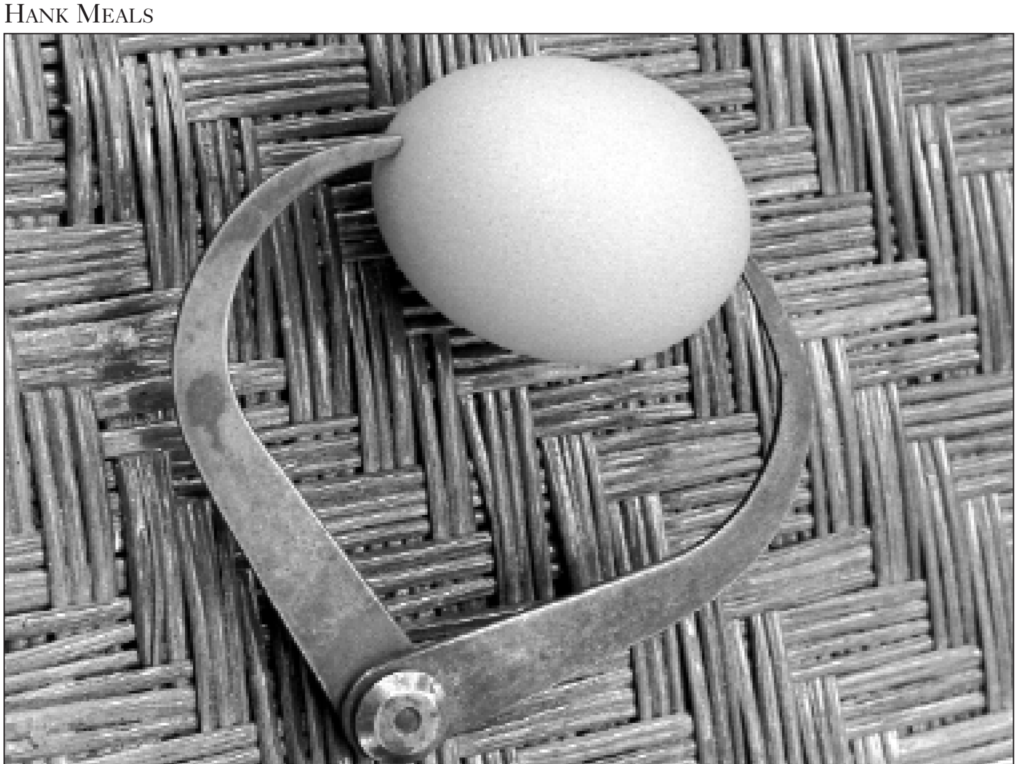

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only give you a predictable, limited array of body types–the core of the taxonomical chart–regardless of how much additional evolution occurs. Of course, living systems are more massive, complex, and multifaceted than atoms, so you can get more subtypes within the major themes as organismic evolution progresses.

When the Darwinian model is upended, what does this imply for human potential?

It does imply a different way of conceiving of potential. I should say that in substituting an alternative view for Darwinism, it's important to utilize and appeal to concepts that are as rigorous, or more rigorous than those identified by genetic determinists. Genetic determinism has claimed the scientific high ground because it deals with the very specific, measurable, quantifiable, tangible entities of genes. I would not want to supplant Darwinism with a paradigm based in the metaphoric or metaphysical. The epigenetic view brings in other causal modalities that are neglected in the standard picture, partly because of the training of biologists. Today a student can go through a university biology program through the Ph.D. without ever taking physics, and miss out on this whole level of causation. The concept of epigenetic-genetic interplay is scientifically more complete than genetic determinism, and genetic determinism is actually obscurantist because it tries to explain things by genes that are genetically inexplicable.

So, to return to your question about human potential, which takes us into the realm of art and poetry, we must recognize that we're dealing with a human brain that, on a physical level, is a highly interactive system in which multiple causalities are brought to bear. To acknowledge this is to be more, not less, scientific. Evolutionary psychologists such as Steven Pinker aspire to rigor by saying it's all in the genes. But if you consider how the evolution of the body occurred over vast amounts of history, and how the outcomes of epigenetic processes have been genetically coopted and assimilated in certain lineages and not in others, you can understand that neural connectivity in the brain has been subject to the same kind of thing. Even though we are partly the product of an immense period of genetic evolution, it does not follow that our thoughts and our ability to imagine are the products of genes. Analyzing the human mind genetically is like trying to interpret *The Divine Comedy* by chemically analyzing the ink it's printed in.

Based on this view of evolution, species boundaries, and epigenetic influences on development, how do you establish lines for what is appropriate or inappropriate in biogenetic engineering?

While it is true that certain versions of genes are associated with certain disease conditions, this is only part of the story. We know the gene and exact site of mutation in sickle cell disease, for example, but we don't know why this disease is mild in some individuals and fatal in others. Similarly for cystic fibrosis and phenylketonuria, the diseases are far more complex than the designation "monogenic trait" would imply. I would say it's rational to use genetic information in a very conservative way–as a prenatal diagnostic. But, the idea of using genetic information as a tool to go back to the embryo and start tinkering with it is not rational at all.

How is the cherished goal of biological perfectibility and the eradication of biological defects through genetic engineering a misguided goal for humans and for evolution?

First, it's easy to fall into language that looks at all deviation from certain norms as being a "disease" condition. For example, it's been noted that if everyone were genetically engineered to be six inches taller, there would still be the same number of people in the lowest quartile of height. I'm on the Board for the Council for Responsible Genetics, Cambridge, MA, which has been considering the social implications of genetic technologies for the past two decades. Although we started with the perspective that the use of genetic information should be left to individuals, we have grown to appreciate how deeply individual thinking about biological variability is influenced by the prevailing eugenic ideology. Even the concept of a birth defect is a relative concept.

It's also pretty clear that our germline and somatic cell genes are under assault by environmental pollutants and the thinning of the ozone layer, and that some birth anomalies are tied to environmental toxins and prescribed and over-the-counter medications. Particular cases of this have often been difficult to establish because it is frequently impossible to distinguish statistically real effects of known toxins from clusters of cases that are randomly occurring, or due to unknown agents. Furthermore, our knowledge of the basis of vulnerabilities to toxins, or synergistic effects among them, is quite primitive.

In any case, because of the interplay of epigenetics and genetics it may be impossible, even in principle, to determine if an abnormal developmental outcome was "environmental" or "genetic" in certain cases. (Many cases, of course, will be less ambiguous). It should be recognized, however, that even if epidemiology does not disclose a clear-cut relationship between a chemical and a type of defect, that does not mean that the chemical did not contribute to the defect. Polluters and manufacturers of suspect drugs will typically want to blame the victim–saying that "bad genes" were the cause of an individual's birth anomaly. Since genetic background influences susceptibility to toxic substances, the logical consequence of genetic determinism will be to screen people's genes and tell them where they can work or live, rather than clean up the environment. In the future, we can even genetically engineer them to have an improved capacity to repair environmental damage to their DNA, a proposal actually made by a well-known Human Genome Project program director at a meeting I attended.

Can we say that the set of problems addressed by genetic engineering is not well-posed–that the causes of human suffering have cultural and societal, rather than genetic sources?

Exactly. Right. People being outside of the norm one way or another is not the problem. My colleague Gregor

Wolbring, a professor of biochemistry at the University of Calgary, was a victim of prenatal thalidomide exposure, but does not consider himself to be a person with birth defects. There's an interesting connection here with the evolutionary ideas I was discussing before. The way that Darwinism accounts for structural innovation is by the accumulation of many incremental changes that are tested at each step for functional advantage or improved adaptation. But people with congenitally missing limbs and other birth anomalies typically reject prostheses and find a way of operating in the world that suits their biology. When we see how thalidomide people relate to the world, and other people with so-called birth defects, we see they typically find a way of operating that suits them. Organisms don't relate to their environment because they've been evolved to match with that environment more and more perfectly, but because they figure out how to make what they have work. For example, there's a community on Martha's Vineyard in Massachusetts in which almost everyone is deaf. Deafness is not considered a defect because that's the way the people there are. So, with epigenesis and creative survival (followed, in many cases, by genetic consolidation) driving evolution, we can throw out the incrementalist perfectionism of Darwinism–it's not needed.

Will you comment on the distinctions to be made between a wild system and one that is biogenetically engineered? At what point does engineering usher in irreversible artifice or domestication for a species and a system?

The idea of the "natural" and the "wild" is out of fashion with many geneticists and evolutionary biologists who see evolution as pure opportunism, lacking any inherent direction. Short of inducing an overt pathology, genetically engineering an organism in this view yields a product with no ontological distinction from a naturally-occurring organism. While I resist romanticizing the "wild," if evolution proceeds in preferred directions, as I have suggested, it becomes harder to sustain the notion that arbitrary genetic changes are as natural as evolved ones. Domestication of animals has been pointed to as an example of human-guided deviation from the wild. I suggest, however, that like natural evolution, but unlike the results of genetic engineering, the phenotypic changes induced by domestication have proceeded in "natural" directions.

There have been some studies going on for over a half-century in Siberia on the domestication of foxes. The geneticist Dmitri Belyaev, who started the whole enterprise, looked at different domesticated animals and saw commonalities among even widely divergent species that had been domesticated, such as dogs, cattle, and pigs. There was a common reshaping of the skull, and even in the pattern of coloration there was a convergence to certain recurrent themes. Belyaev and his colleagues decided to try it with foxes, a species that had never been domesticated before. They found that in just a couple of generations the same changes occurred that had occurred in other, unrelated lineages. They found that if animals are selected for docility–a common mode of domestication–then the maternal environment of the embryo contains decreased levels of aggression-associated hormones. This in turn affects the course of the embryo's development, delaying certain processes and accelerating others, altering fetal form and physiology. While the investigators have hypothesized that their initial selection for docility was a selection for genetic variants, this is just a speculation, although one that is understandable from Russian biologists eager to avoid a Lysenkoist taint. It is also known, however, that phenotypic differences may even exist between genetically identical individuals. What is clear is that the motive force of the morphological changes observed in this study was epigenetic–a changed gestational environment. Moreover, common epigenetic processes seem to be involved in the convergent effects of domestication of genetically divergent species. It is not too much of a stretch to imagine that the transition from ape to human occurred through such epigenetic causation, brought about by self-domestication. After all, we share more than 98 percent of our genetic sequences with chimpanzees. The standard idea, of course, is that the unshared 2 percent is what makes all the difference.

It seems to me most critical to consider how biogenetic engineering will contribute to an increasingly domesticated world and to draw the lines for its implementation on those terms.

From what I have described above, wild and domesticated forms are both varieties of the "natural." The writer Paul Shepard has discussed many reasons to value and preserve wild forms, which of course are different in profound ways from their domesticated counterparts. But from a strictly biological point of view, according to which even the human species, at least up till now, is "natural," I would counterpose wild and domesticated species on one side to genetically engineered forms, which I see as tending toward the status of artifacts. Advocates of genetic engineering claim that it is no different from what evolution has done, and that it is in fact a new form of evolution. But genetically engineered crops are not analogous to products of normal evolution. If epigenetic causation is the motor of evolution as I have proposed, and genes play a subordinate, consolidating role, then going at the properties of an organism by manipulating its genes is not even really "engineering." It is the hit-or-miss production of potentially useful monstrosities.

The current period is characterized by a growing drive to turning the living world into a collection of manufactured artifacts. Already the legal system says that if you make a genetic modification in an organism it's a human invention, it's not part of nature. This was the stated majority opinion on the Supreme Court in its 1980 Chakrabarty decision, which affirmed the right to patent organisms. I don't have anything against manufactured items, and will even acknowledge that genetically modified microorganisms may be useful. I use them in my own research. But I am dead set against patenting them. This takes the threat of blurring the distinction between organisms and artifacts that is implicit in genetic manipulation and turns it into a legal and cultural reality. The

Chakrabarty patent was for an oil-eating bacterium. Since then it has served as a precedent for the issuing of patents on mice, pigs, and cows, some containing introduced human genes, as well as naturally occurring human bone marrow cells. There is no U.S. regulation that would forbid a patent on a genetically modified first-trimester human embryo–and such things would indeed be useful and commercially viable.

Do you see an irreversible threat to natural systems and evolution with transgenic introductions?

I do. There's a thicket of ideology that surrounds all of this that is important to understand. The biologist E.O. Wilson and his followers say that evolution is totally opportunistic, based on the harshest of organism-organism and organism-environment interactions, but, at the same time, the products of evolution are love-inspiring. They speak of "biophilia," our love for the living products of nature. Yet, as the philosopher Hans Jonas notes, from a Darwinian viewpoint evolution is nothing but the successive elaboration of "pathologies." In my view it is not enough to say that although life is the result of arbitrariness and opportunism we should love it just because that's what we happened to get. Of course many modern Darwin-influenced thinkers aren't as ardent as Wilson–they just think it's all meaningless. Another somewhat one-sided view of living organisms has arisen with applications of the mathematical field of complex systems theory. Although this approach seeks to identify living processes with dynamical phenomena neglected by genetic reductionism, it in turn ignores an organism's accumulated legacy of jury-rigged gene-based stabilizing mechanisms. If we look at a modern organism, we see that it is a composite system that bears the stamp of originating, self-organizing processes, but also exhibits the incredible integration and consolidation that results from vast periods of genetic evolution. As a result, the living systems that we are familiar with are very different from nonliving systems–even self-organizing dynamical systems.

How can we understand the question of what life is in a way that enables us to put biotechnology into perspective?

Biology or at least biology as a traditional vocation–which is to understand what life is and how it works–is very different from biotechnology. Now the distinction has become blurred because of the commercialization of organisms, and because the ideology of the gene collapses everything into a single thing that can be sequenced, modified, bought and sold. People too easily confuse the manipulations technologists can do for the types of things that evolution has done. Darwinists will say evolution isn't wise, it's just whatever works. I wouldn't want to anthropomorphize evolution and say it is wise, but neither is it arbitrary.

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