Materialism, Emergence, and Life: The Interaction of Gene, Organism, and Environment*

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Through critically engaging the work of natural scientists, social scientists can develop a richer understanding of the natural world (including human life), leading to a greater comprehension of the complex set of interactions which makes life anything but mechanistic. Given the steady flow of news reports on genetic cloning, genetically modified organisms, and patents on genes, social scientists have an obligation to grapple with the debates currently taking place within the natural sciences. Through this encounter, sociologists can enhance our understanding of natural and social relationships. Lewontin's *It Ain't Necessarily So*, a collection of essays originally published in *The New York Review of Books*, provides a searing critique of scientific knowledge while tackling issues as diverse as heredity, intelligence, cloning, gender, evolution, and genetic engineering. Lewontin's essays are lucid and insightful, addressing the paramount debates of our time. Both Lewontin's *The Triple Helix* and Oyama's *The Ontogeny of Information* critique dominant conceptions within evolutionary, biological, and developmental sciences, while illustrating the importance of

* The main works under consideration in this review essay are *It Ain't Necessarily So: The Dream of the Human Genome and Other Illusions*, 2nd edition, by Richard Lewontin (New York: New York Review Books, 2001); *The Triple Helix: Gene, Organism, and Environment*, by Richard Lewontin (Cambridge: Harvard University Press, 2000); and, *The Ontogeny of Information: Developmental Systems and Evolution*, 2nd edition, by Susan Oyama (Durham: Duke University Press, 2000). I wish to express my gratitude to John Bellamy Foster, Jason W. Moore, Thembisa Waetjen, and Denis Wall for their helpful comments and suggestions.

a materialist and dialectical approach toward understanding the internal and external processes operating throughout nature. Given that humans are living creatures, dependent upon and part of nature, this discussion speaks directly to us.

Sociology moves beyond the ideology of bourgeois society, which places the individual "ontologically prior to the social," by understanding society as more than "the outcome of the individual activities of individual human beings" (Levins and Lewontin 1985:1). Nevertheless, sociology often neglects to account for the internal structure of individuals (as organisms) as well as the external environment (nature) in analyses of society, life, and history. Part of this is due to an aversion to positivism, but it is also linked to a retreat from materialism in the social sciences. While teleological and mechanistic explanations must be avoided, a materialist conception of nature, which is both ontological and epistemological, allows for an approach that is realist and relational (Foster 2000:6-7). The social is dependent upon the physical-biological world. In fact, society is part of nature and it emerges in relation to the latter. At the same time, each realm has an independent existence, while transforming the other through their interactions. The development of this relationship is not predetermined; the future remains contingent. With this materialist approach, we may reject the breach between the natural and social sciences (Bhaskar 1998). Each realm must be studied on its own terms as well as in relation to the other.

Social scientists, with the exception of sociobiologists such as Edward O. Wilson, generally, stand against biological and genetic determinism. The influences of social structures on life chances and personal development are asserted in opposition to the arguments represented in *The Bell Curve* (Fischer et al. 1996). Inequalities are grounded in social-historical dynamics, rather than in inherent characteristics. Such a critique demonstrates the strengths of sociological inquiry. Unfortunately, the scientific studies themselves are not often subjected to close scrutiny when refuting their claims. Fortunately, scientists such as Stephen Jay Gould (1981), with his devastating critique of the inheritance of intelligence and its basis for social ranking, and Lewontin, in his dismantling of biological explanations for why humans act as they do (Lewontin et al. 1984), investigate the speculation, fabricated data, and ideological agenda behind the proponents of genetic and biological explanations for social hierarchies and organization. At the same time, Gould and Lewontin make the natural sciences, especially topics such as genes and evolution, accessible to the general population, allowing the public to be informed when encountering scientific claims.

Materialism and Coevolution

In *The Triple Helix*, Lewontin insists that the relationships and interactions between gene, organism, and environment are central to understanding evolution. In the past, these realms have been separated, allowing for our knowledge of natural selection to advance. But in order to continue to move forward the relationships, between the internal and external processes of life, must be conceptualized as a whole. Failing to do so neglects the complexity of biological processes and the dynamic character of life.

Science uses metaphors, such as Descartes's characterization of the world as machine, to help explain the workings of the world, especially those phenomena that are not directly seen or experienced by humans (*Triple Helix*, p. 3). While metaphors are useful, too often science confines research to such efforts that only reinforce and reify the principles of the metaphor, overlooking information that lies outside of the metaphorical approximation (ibid: 4). Developmental biology is caught within the blinders of metaphor. "*Development* is a metaphor," Lewontin notes, "that carries with it a prior commitment to the nature of the process. Development ... is literally an unfolding or unrolling of something that is already present and in some way preformed" (ibid: 5). To illustrate this point, in the eighteenth century preformationists contended that the adult organism was already formed and contained in the sperm and that development was the continuation of this being into life. In opposition, the theory of epigenesis proposed that an organism was not "formed in the fertilized egg, but that it arose as a consequence of profound changes in shape and form during the course of embryogenesis" (ibid: 5-6). While the picture of a miniature human organism in a sperm now seems ridiculous, developmental biology has embraced a similar position, contending that there is already a finished blueprint of the organism, along with all the necessary and required information to specify it, within the genes. Development assumes that the organism 'develops itself.' The environment becomes background, or simply a basis, for enabling the genes to 'express themselves.' Living beings become 'only outward manifestations' of internal forces. Developmental biologists focus on the similarities between individual organisms while ignoring or dismissing variation. Common characteristics are reduced to mechanistic operations of genes. Change is predetermined, following an ascribed path until death.

Prior to World War II, biological determinism ascribed social, cognitive, and psychological differences to genes. But with the rise of Hitler and the application of theories of race towards extermination, environmental theories of variation became more popular as a way of countering biological reductionism. Despite this, however, scientists (both social and natural) failed to provide a comprehensive explanation for social and biological changes. So now, along with a shift to the right in politics, genetic explanations reign. Working from within assumptions, developmental biologist see the development of an individual as an unfolding of the genetic blueprint, while any variation that exists between individuals is explained as the result of variations within the program specified by the genes (ibid: 17). Thus, differences in social position, school performances, sexual preferences, and intelligence are seen as the consequences of genetic variations between individuals, rather than being consequences of factors outside the model.

Lewontin characterizes this type of reasoning and science as bad biology. While noting that it is true that "lions look different from lambs and chimps from humans because they have different genes," Lewontin asserts, "if we want to know why two lambs are different from one another, a description of their genetic differences is insufficient and for some of their characteristics may even be irrelevant" (ibid: 17). Arguing that an organism does not compute itself from genes, Lewontin explains "that the ontogeny of an organism is the consequence of a unique interaction between the genes it carries, the temporal sequence of external environments through which it passes during its life, and random events of molecular interactions within individual cells. It is these interactions that must be incorporated into any proper account of how an organism is formed" (ibid: 17-18).

The organism becomes a site of interaction between the environment and genes. Specific historical conditions influence the conditions of an organism's emergence. A dialectical influence is constantly associated with changes throughout life. Lewontin notes that while "internally fixed successive developmental stages are a common feature of development, they are not universal" (ibid: 18). For example, the morphology of the tropical vine *Syngonium* varies depending upon incidences of light conditions. The shapes of its leaves, as well as their spacing, changes along with the environmental conditions. Furthermore, taking a plant such as *Achillea millefolium* and cutting it into separate pieces can show the importance of environmental influences on the physical manifestations of an organism. The pieces will each grow into new individual plants, regardless of whether each piece is placed in different environments, including differences in elevation. The plant growth, shape, and size drastically vary between environmental conditions (ibid: 20). While the plants were genetically identical, there was "no correlation of growth pattern from one environment to another" (ibid: 22). What such studies illustrate is that "the organism is not specified by its genes, but is a unique outcome of an ontogenetic process that is contingent on the sequence of environments in which it occurs" (ibid: 20).

With regard to the increasing awareness of an environmental crisis and the importance of the environment to human society, Barry Commoner once remarked that "[t]he environment has just been rediscovered by the people who live in it" (1971:5). In a similar fashion, Lewontin is challenging the natural sciences, including evolutionary and genetic sciences, to reconceptualize the importance and role of the environment in the emergence of organisms. The same objective is being undertaken within sociology, specifically environmental sociology.

Darwin took an important step in evolutionary science "by alienating the inside from the outside: by making an absolute separation between the internal processes that generate the organism and the external processes, the environment, in which the organism must operate" (*Triple Helix*, p. 42). He had to make this distinction to free science from the "obscurantist holism that merged the organic and the inorganic into an unanalyzable whole" (ibid: 47). As a result, Darwin was capable of recognizing that variation is an internal process, causally independent of nature. From this point, diversity was seen as a consequence of diverse environments "to which different species have become fitted by natural selection. The process of that fitting is the process of *adaptation*" (ibid: 41-42). The interaction of the organism and the environment took place through a selective process, where an organism fit into an ecological niche. The notion of a niche implies a predetermination, a hole in nature, which is filled by an organism, rather than a transformation on the part of either the environment or the organism (ibid: 43-44).

Lewontin argues that while it is true that the internal process of heritable variation is not casually dependent on the environment in which organisms live, "the claim that the environment of an organism is casually independent of the organism, and that changes in the environment are autonomous and independent of changes in the species itself, is clearly wrong" (ibid: 48). Rather than adaptation, the process of evolution is best described as a process of construction. Organisms actively transform the environment through living, although the conditions of the environment are not wholly of their own choosing, given that previously living agents historically shaped nature. Niches come into being as a result "of the nature of the organisms themselves" (ibid: 51).

The dialectical interchange between the environment and the organism becomes a central tenant of the coevolutionary position being proposed. Lewontin asserts, "[j]ust as there can be no organism without an environment, so there can be no environment without an organism" (ibid: 48). Independent forces and processes operate in nature. Glacial ages and volcanic eruptions can occur independently, but these are physical conditions. "An *environment*," notes Lewontin, "is something that surrounds or encircles, but for there to be a surrounding there must be something at the center to be surrounded" (ibid: 48). The life activities of organisms will "determine which elements of the external world are put together to make their environments and what the relations are among the elements that are relevant to them" (ibid: 51). The metabolism, sense organs, shape of the organism, and nervous system, both within a species and between species, influences the "spatial and temporal juxtaposition of bits and pieces of the world that produces a surrounding for the organism that is relevant to it" (ibid: 52). Organisms are in a constant state of interaction with the natural world, thus they are constantly altering the world around them (ibid: 55). Alfred North Whitehead emphasized that the body is part of the external world, as it processes food and takes in air for its survival (1968:21). Lewontin frames this relationship in more detail noting that organisms are constantly taking in the world around them through their consumption, but in this process, consumption is also production, as the physical conditions are changed in meeting the needs of organisms. Given that living beings must transform nature for existence, all organisms "alter not only their own environments but also the environments of other species" (*The Triple Helix*, p. 55).

Recognizing that the environment can change independently of organisms, Lewontin incorporates a discussion of organisms' responsive abilities, such as the rates and forms of reproduction, which vary in invertebrate animals, according to changes in space and time (including temperature, weather, etc.) of the world surrounding them (ibid: 62-64). He explains, "[w]hatever the autonomous processes of the outer world may be, they cannot be perceived by the organism. Its life is determined by the shadows on the wall, passed through a transforming medium of its own creation" (ibid: 64). Furthermore, "life as a whole is evolving in external conditions that are the consequence of the biological activities of that life" as well as all life preceding it (ibid: 66).

Change is the rule of life. Organic processes are historically contingent, defying universal explanations (ibid: 76). Lewontin rejects teleological conceptions of evolution:

> All species that exist are the result of a unique historical process from the origins of life, a process that might have taken many paths other than the one it actually took. Evolution is not an unfolding but an historically contingent wandering pathway through the space of possibilities. Part of the historical contingency arises because the physical conditions in which life has evolved also have a contingent history, but much of the uncertainty of evolution arises from the existence of multiple possible pathways even when external conditions are fixed. (Ibid: 88)

Rather than conceptualizing the natural world in rigid relationships, a dynamic approach is needed to embody the dialectical relationship of coevolution:

> The relations of genes, organisms, and environments are reciprocal relations in which all three elements are both causes and effects. Genes and environment are both causes of organisms, which are, in turn, causes of environments, so that genes become causes of environments as mediated by the organisms. (Ibid: 100-101)

Organisms are emergent, involving both internal and external dynamics. So long as genes, organisms, and environments are studied separately, our knowledge of the living world will not advance.

There is no evidence that organisms are becoming more adapted to the environment. Evolution does not entail a drive towards perfection. All elements in the triple helix (gene, organism, and environment) are changing. Around 99.99% of all species that ever existed are extinct (ibid: 68). Likewise, there is no evidence for claims of harmony and balance with the external world. Environmental change will continue. Natural and social history is in constant motion. Chance is always present. "What we can do," Lewontin emphasizes, "is to try to affect the rate of extinction and direction of environmental change in such a way as to make a decent life for human beings possible. What we cannot do is to keep things as they are" (ibid: 68). Informed social action, which includes knowledge of the interaction between the natural and social worlds, is necessary in order to properly navigate history in the making.

Oyama's *The Ontogeny of Information* undertakes a project similar to Lewontin's by analyzing complex interactions in multileveled developmental systems both within organisms and between organisms and their environment. Oyama contends that development in organisms and information does occur, in so far as the prior structure is transformed through interaction (*Ontogeny*, p. 4). In this position, she moves away from the developmental biologists' belief that development is an unfolding process. One of the goals of Oyama's work is to step outside the confines of the nature-nurture debate in order to illustrate that nature and nurture are developmental products and developmental processes that produce human development. Notions of predeterminancy are not useful regardless of whether they utilize internal or external explanations. An understanding of life must be founded upon a relational model of inquiry.

Oyama views ontogenesis as an inquiry into the state of becoming, or the emergence of an organism (ibid: 3). The organism is the nexus between internal and external worlds. In the process of emerging, an organism uses and organizes information, which is already organized by previous interactions of organisms with the external world. Oyama insists that a conception of information must entail a variety of meanings, given that it can exist in the environment, tissues, genes, etc. Information is not preordained, but it is orderly, due to the conditions of life. Like Lewontin's characterization of the environment and organism as dependent and interacting realms, Oyama contends that information comes into existence only in the process of ontogeny.

Rather than proposing that ontogeny is the result of genetic information unfolding, Oyama argues that the organism and environment are creations of an interaction between them. Organisms hold a central role in creating their environment; they are the point of organization. Both DNA and the external world only have meaning and causation so long as they interact simultaneously through the nexus of the organism. Oyama notes that the transformations and developments that occur are the result of the existing information in genes, cells, tissues, and the environment, as well as the alternatives that are possible at that point in time, given the existing historical conditions. She links this approach to Lewontin's relational, materialist coevolution (ibid: 18).

Oyama argues against prescriptive theories for ontogeny. History is an important and necessary consideration for all analyses, but Oyama emphasizes that many scientists fail to consider the importance of the present in the immediate construction of information. Historical considerations are essential for understanding the present conditions and information, but as an organism continues to develop it is processing the historical in terms of the present (ibid: 13). There is immediacy in the state of becoming.

By way of heredity, Oyama argues that

> genes do not create traits according to a plan written in their very structure, even by operating on conveniently available "raw materials," if phenotypic characteristics arise only when sufficient interactants are present in the proper place and at the proper time, and if all these factors are therefore given comparable causal and formative significance, *then defining heredity as the passing on of all developmental conditions, in whatever manner*, is preferable to defining it by genetic information. (Ibid: 43)

In addition, she indicates that "[w]hat induces variation, and how much variation results, depends on what the character is and what the conditions are" (ibid: 44). With Lewontin, Oyama holds to the view that organisms transform and create niches and "the evolution of the organism itself changes those circumstances" (ibid: 45). Evolution is an interactive process whose "constraints and causes emerge as it functions, as they do in a developmental process" (ibid: 45). Organisms are in a state of transformation, emerging under historical and structural constraints.

The theory that ontogeny is genetically directed development must be abandoned. Genes that do not exist cannot be transcribed, but even genes that exist may not be transcribed, given the history of a cell, environmental influences, and mutations. The genetic information produced depends upon the rest of the developmental process, on effective stimuli, and effective information throughout an organism (ibid: 80). The developmental process of information is a complex series of interactions. Many stimuli may call out for a variety of responses from an organism, but what is produced, created, and acted upon varies. Thus the development of an organism is not a predetermined and predicable process. It is dynamic. It is emergent. Oyama argues this position in opposition to teleological notions, such as the hand of god, as well as human interjections of purpose, in regards to the development of life:

> There are no ghosts in machines, only persons in the world, thinking, feeling, intuiting and sensing, deciding, acting, and creating. And there are therefore no ghosts in these ghosts, no programs in the operators of the machines, making them feel as their ancestors felt, making them act or want to act as gorillas or chimps act. But there *are* many ghosts in the psychological, social, and cultural machines that create and re-create the body-machine, the ghost in it, and the ghost in *it*. (Ibid: 128)

Like Lewontin, Oyama insists that a dialectical approach is needed for understanding living organisms, as well as the interactions between living things and the environment:

> The point of interactionism is not that everything interacts with everything else or that the organism or genome interacts with everything. Nor is it that everything is subject to alteration. It is rather that influences and constraints on responsiveness are a function of both the presenting stimuli and the results of past selections, responses, and integrations, and that organisms organize their surroundings even as they are organized by them. This being the case, developmental pathways are not set in any substantive way either by genome or by environment, regardless of the normality or relative probability of the pathway itself. (Ibid: 169)

The natural and social sciences cannot be separated any longer (ibid: 125). They need to inform each other so that a better picture of the world might be gained. A materialist approach provides the basis for understanding the foundation from which life is based, the source of such information, and the realm of interaction. "Nature is not an a priori mold in which reality is cast," Oyama recollects, "[w]hat exists is nature, and living nature exists by virtue of its nurture, both constant and variable, both internal and external" (ibid: 148). Oyama's goal is to enrich and broaden our ideas of causality by locating information in the context of processes that produce and reveal it, while placing ourselves in the middle of the tangled bank of life (ibid: 192). In this effort, both Lewontin's *The Triple Helix* and Oyama's *The Ontogeny of Information* illuminate the importance of a coevolutionary perspective for understanding the complex biological world in which human society and all life is immersed.

From the Human Genome to Genetically Modified Foods

It Ain't Necessarily So collects Lewontin's essays on genetics, evolution, and science that originally appeared in *The New York Review of Books*. Drawing upon his knowledge as an evolutionary biologist and geneticist, Lewontin provides a lucid analysis of the debates and politics surrounding genetics and evolution. He renders subjects such as heredity, human cloning, the Human Genome Project, and genetic engineered food to a critical analysis, both confirming what we know about life and ourselves and debunking the false premises and exaggeration of our biological knowledge. Moving from evolution to the Human Genome Project to genetic engineered food, Lewontin's materialist analysis provides a thorough examination of the workings of genes and the social relationships surrounding this science. His dialectical approach challenges the genetic and biological determinism that is all too common these days.

Lewontin argues that everything in the material world is not knowable. There is not enough time and, besides, the many forces operating, such as selective forces on genes, are so weak that they cannot be measured. There will always be the unknown within the physical world. As a result, scientists tend to ask questions they can answer. Science is a social activity, commonly reflecting the reigning ideology of society and the ambitions of the political sphere (*Ain't Necessarily So,* pp. xxvii, 10-11). Biological determinism is a political necessity arising after the bourgeois revolution to reconcile the ideology of equality in the social context of mass inequality in status, wealth, and power. A natural explanation, based on artificial attributes, such as intelligence or good genes, provides new paint for the walls of empire. As a result, equality is reduced to equality of opportunity. Failure to succeed is due to intrinsic qualities, not social organization (ibid: 17-18). Rooting social inequalities in the conditions of society, Lewontin stands at the forefront of the struggle to dismantle the biological determinist position. In the process, he illustrates how biological processes work and how social relations influence changes in the biological world.

Lewontin points to two post-Renaissance revolutions in biology. First, Descartes proposed mechanistic biology. Second, Darwin's materialist explanation for evolution, which removed the hand of god, explained changes in species through natural selection (ibid: 44-45). Lewontin continues in this materialist tradition, while proposing further progress in our understanding of life, arguing that organisms are "the unique consequence of a developmental history that results from the interaction of and determination by internal and external forces" (ibid: 147).

Given the constant barrage of genetic claims for almost every character trait imaginable, Lewontin's discussion of genes and the Human Genome Project prove to be enlightening, while shattering the fetishism of DNA. Commoner states that with the discovery of DNA, genetic scientists view its molecular structure as the agent responsible for the inheritance in all living things, making the DNA gene the "absolute monarch" (2002:39). Lewontin notes that the mythology surrounding the DNA molecule entails the notion that it is self-reproducing, allowing for its own duplication since the first combination of sperm and egg, as well as self-acting, imposing a specific form dictated by its own internal structure on an undifferentiated fertilized egg (*Ain't Necessarily So*, p. 139). In explaining the relationship between DNA and genes, it is commonly stated that

> DNA is composed of basic units, the *nucleotides*, of which there are four kinds, adenine, cystosine, guanine, and thymine (A, C, G, and T) and these are strung one after another in a long linear sequence which makes a DNA molecule. So one bit of DNA might have the sequence of units ... CAAATTGC ... and another the sequence ... TATCGCTA ... and so on. A typical gene might consist of 10,000 basic units... The DNA messages specify the organism by specifying the makeup of the proteins of which organisms are made. A particular DNA sequence makes a particular protein according to a set of decoding rules and manufacturing processes. (Ibid: 139-140)

Furthermore, DNA is depicted as though it recreates itself through the unwinding of the double helix, while nucleotides match up to complement the adjacent nucleotides on the strand, until a new strand of DNA is created (ibid: 141). Lewontin states that this story is correct in detailed molecular description, but it is "wrong in what it claims to explain." First, "DNA is a dead molecule;" it cannot self-reproduce. "It is produced out of elementary materials by a complex cellular machinery of proteins. While it is often said that DNA produces proteins, in fact proteins (enzymes) produce DNA," Lewontin continues, "[n]o living molecule is self-reproducing. Only whole cells may contain all the necessary machinery for 'self'-reproduction and even they, in the process of development, lose that capacity" (ibid: 141-142). Additionally, DNA is incapable of making anything, including itself. The sequence of nucleotides in DNA is used by the machinery in "the cell to determine what sequence of amino acids is to be built into a protein, and to determine when and where the protein is to be made. But the proteins of the cell are made by other proteins, and without that protein-forming machinery *nothing* can be made" (ibid: 143). DNA only holds information that is utilized by the cell machinery in its own productive process. Both DNA and cell machinery, composed of proteins, are inherited. And as emphasized earlier, an "organism does not compute itself from its DNA," rather it emerges "from the interaction of and determination by internal and external forces" (ibid: 147). Plus, the environment, which is the external force, is partly "a consequence of the activities of the organism itself as it produces and consumes the conditions of its own existence." Organisms are also subject to random cellular movements and chance molecular events. Variation is central to cellular reproduction. Even with the same genes and environmental conditions, one side of a fly differs from its other side, just as fingerprints between a person's left and right hand vary.

To complicate matters further, code sequences (i.e. TATCGCTA) may be exactly the same, but the code can have more than one meaning. For example, a code could be an instruction to insert the amino acid valine in a protein, but it could also be a spacer in a sequence. It is not known how the cell "decides among the possible interpretations" (ibid: 152-153). As a result, the Human Genome Project will never be capable of definitively knowing what each DNA sequence means, given that the meaning can change and vary. Commoner (2002) reflects that the Human Genome Project collapsed under the weight of its own discovery. It was asserted that genes made proteins, but it was discovered that "there are far too few human genes to account for the complexity of our inherited traits or for the vast inherited differences between plants, say, and people" (Commoner 2002:40). Humans are estimated to have around 32,000 genes, while a mustard weed has 26,000 genes. The gene count is too low to match the number of proteins and the inherited traits they engender. Thus genes cannot provide the ultimate description of life (ibid: 42).

Molecular biology and genetics is big business. The net of genetics has been cast wide under its definitive claim to explain life. The Human Genome Project costs billions of dollars to operate, so the project is always framed as if its work serves the public good and helps make a better society. Claims have been made that genetic research will help discover the genetic impairments of the homeless (*Ain't Necessarily So,* p. 165). Lewontin takes special notice of how this ideological veil ignores the power structure within society, where groups compete for profits, where pharmaceuticals file patents on medicines to control distribution and accumulation of capital, and where the operation of the economic system creates unemployment (ibid: 162-166). Molecular biologists are entrepreneurs. Genes are isolated and patented. While patent law prohibits the patenting of anything that is 'natural,' scientists claim that isolated genes are not natural, despite the fact that the organism that they are taken from are. Through this sleight of hand, corporations have been able to patent genes, controlling the manufacture and distribution of pharmaceuticals. Private interests dominate this research in opposition to the public good.

Faced with the knowledge that "genes only specify the sequence of amino acids that are linked together in the manufacture of a molecule called a polypeptide, which must then fold up to make a protein," a call for a massive proteome project has been proposed (ibid: 191-192). Polypeptides can fold, resulting in different proteins. The folding can take place in many different ways in different cells of various organisms. It may also be dependent upon small molecules like sugar and other proteins. Any project to unravel this matter will be much more expensive and it will take much longer than the Human Genome Project. The spiral of research feeds upon itself and the notion that life will be revealed in these isolated studies continues to permeate through the public, as biological explanations attempt to justify existing social inequalities.

Genetic research on plants has been even more intrusive given the direct manipulation of organisms. Through genetically modified organisms (GMOs) and patented seeds, capital, via biotechnology, continues to transform and extend their control over the organization of agricultural production (Lewontin 2000:93, 100; Kloppenburg 1990). Much debate has arisen over the use of GMOs, yet clarity has not been a strong point in these arguments. Fortunately, Lewontin cuts through the muck of ethical issues to articulate a clear and concise critique of GMOs from his understanding of genetics. He begins by insisting "human beings have been genetically modifying organisms since the first domestication of plants and animals" (*Ain't Necessarily So*, p. 345). Through continuous seed selection, the organisms of today are very different from their wild ancestors. Corn has become a crop that cannot survive independent of human care, because the compact ear with large kernels packed tightly to the cob does not allow for seed dispersal. But it does provide an abundance of food, which can be gathered and stored for long periods of time.

Seed selection, in the past, involved a search for desirable variants, such as drought resistant, and the propagation of those selected seeds (ibid: 346). Furthermore, under conditions of domestication, closely related species, which do not interbreed in nature, were interbred to produce new variations. Human beings constantly transform nature in the process of food production, changing the evolutionary development of plants throughout the world. This process is a requirement for the continuation of life, but the way this interaction is organized is attributable to social relationships.

Capitalist interests have largely dictated the developments in genetic engineering. DNA is extracted from a donor organism and then inserted into the cells of a recipient, so this DNA becomes part of the genome (ibid: 347). This process creates a transgenic organism; now, generally known as a GMO. The primary use of transgenic DNA transfers, in agricultural research, has involved making crops resistant to insect pests and/or herbicides used to control weeds. Given that all the major seed companies are owned or tied to chemical companies illuminates the interests in creating organisms resistant to herbicides (Middendorf et al. 2000:110). As far as resistance, Lewontin explains that "genes coding for powerful toxins, the Bt proteins, from a bacterium, *Bascillus thuringensis*" are introduced into an organism (*Ain't Necessarily So*, p. 348). The plants manufacture these proteins internally, so when bugs nibble on the plants, they ingest the toxin and die.

Transgenic transfer opened the door to transferring any gene in any species to any other species. Of course, some transfers will be harmful or lethal to the recipient, "but there are no general rules to tell us what will work" (ibid: 348-349). The popular concerns regarding GMOs are threats to human health, disruption of the natural environment, and threats to agriculture production from the evolution of resistant pests and weeds (ibid: 351-352). But critiques often fail to acknowledge that conventionally bred organisms have produced adverse effects on other species in nature in addition to causing risks to human health, including "foods like peanuts or milk to which some people are naturally allergic" (ibid: 353). Furthermore, invasive species from distant geographical regions have created problems for agriculture independently of GMOs. If a cross between GMOs and weeds occurs, the offspring will be hybrids which, like cultivated varieties, are "so ill-adapted to survival in nature" that they will be dependent upon contemporary agricultural practices (e.g. unnaturally high levels of nitrogen) for their survival (ibid: 357).

Lewontin raises these points to clarify the risks that are truly unique to the development of GMOs. Rather than focusing on the physiological effect of the genes introduced to the recipient, Lewontin insists that it is *where* genes are inserted in a recipient's genome that poses a serious danger:

> Genes consist of two functionally different adjacent stretches of DNA. One, the so-called structural gene, has information on the chemical composition of the protein that the cell will manufacture when it reads the gene. The other, the so- called regulatory element, is part of a complex signaling system that concerns where and when and how much protein will be produced. When DNA is inserted into the genome of a recipient by engineering methods it may pop into the recipient's DNA anywhere, including in the middle of some other gene's regulatory element. The result will be a gene whose reading is no longer under normal control. (Ibid: 354)

The consequences are unknown. Either the gene is never read at all, serving no purpose as an agricultural variety, or the cell may read the gene, causing it to

> produce vast amounts of a protein that ordinarily is produced in very low amount, and this high concentration could be toxic or be involved in the biochemical production of a toxin. Yet another possibility is that a toxic substance that used to be produced only in one part of a plant, not ordinary eaten, could now be manufactured in another part. (Ibid: 354-355)

For example, tomato plants, which contain toxins in the leaves and stem, could through genetic engineering, start producing toxins unintentionally in the fruit itself. Thus "genetic engineering itself has a unique ability to produce deleterious effects," which justifies that all GMO varieties need to be "specially scrutinized and tested for such effects" (ibid: 355). But how to go about this is not known, given "the unknown nature of the danger." It cannot be controlled given the nature of genes and the development of an organism. While capital, in its intrusion into agriculture, tries to control plants for the accumulation of wealth via the sale of seeds, herbicides, pesticides, and food, it creates new uncertainty, which could potentially have devastating consequences for human health.

Over the last hundred years, industrial capital has transformed farming. Farmers were pulled into the market through specialization, which increased their purchases of other food and household necessities on the market. Seeds, feed, fertilizer, pesticides, and machinery are all purchased from monopoly capital. Initially, with the introduction of new technologies, farmers' yields increased, but this drove the prices down (ibid: 366). At the same time, the costs of production increased. Debt and bankruptcies plague farmers. Ties to monopoly capital have turned "the independent farmer into an industrial employee" (ibid: 367). Lewontin notes, "the creation and adoption of genetically modified organisms are the latest steps in this long historical development of capital-intensive industrial agriculture." Given that humans are structurally and historically organized and are part of the environment, we remain an external force, influencing the evolution of other organisms and transforming the world in which we live, including ourselves.

In 1864, George Perkins Marsh remarked that humans had transformed the earth, often in devastating ways, in the process of obtaining their livelihood (Marsh 1864:11; Clark and Foster 2002:167-169). Social-historical forces influence human interactions with nature, both positively and negatively. As Lewontin sees it, capitalist intrusion into agriculture is radically transforming the evolution of plants. The value of each of these three books is that they demonstrate the social and natural reality as it is given in the material world. Lewontin and Oyama confront the currently prevalent biological and genetic determinist claims. Both of them directly engage issues related to the interactions between genes, the organism, and the environment (which includes society). In the process, they refute teleological and mechanistic approaches to nature and life. A materialist and dialectical approach provides the grounding for these authors to grapple with the complex biological and social processes of the natural world. Life becomes an emergent process and variation holds possibility. A coevolutionary position is developed such that organisms are both the subject and object of evolution adapting and creating their environments. Life is in constant flux, making change the norm. In 1926, Vladimir Vernadsky (1998) proposed that life was a transforming agent, through its interchange with the existing environment, in the creation of the biosphere. The centrality of life in the creation of the world cannot be eclipsed by the reductionistic notion that DNA is the secret to life. As Barry Commoner writes, "DNA did not create life; life created DNA" (2002:47).

Humans remain active agents with the potential to change the social and natural conditions of the world. An informed position, with regard to the dominating social forces of society and the dynamic characteristics of evolving life, is needed to regulate human interactions with nature to whatever degree is possible. As Lewontin remarks, in *The Triple Helix*, we must "try to affect the rate of extinction and direction of environmental change in such a way as to make a decent life for human beings possible. What we cannot do is to keep things as they are" (p. 68).

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