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Molecular Genetics, Evolution, and Torah Principles

At the end of *Hilkhot Teshuvah*, Rambam states that "commensurate with the knowledge [of God] will be the love [of Him]."[1] Indeed, Rambam maintains that the twin obligations to love God and to stand in awe of Him are fulfilled through scientific inquiry and the accumulation of scientific knowledge. Through scientific study one comes to appreciate God's wisdom (resulting in love, *ahavah*) and, in addition, to understand the insignificance and lowliness of the human being in the cosmic order (resulting in awe, *yir'*ah).[2] It is with this view in mind—that scientific study can enhance religiosity— that we approach the issue of how molecular genetics should be viewed within the perspective of Torah.

We live in an era of scientific revolution. There is an intense demand to understand how human genes influence behavior and impact upon health and disease. The scientific gains that have accrued from work in molecular genetics come, in part, through the study of evolutionary

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biology, and evolution is intensely debated throughout our American educational system. Therefore, there is an urgency to understanding the nexus between these scientific studies and teachings of Jewish tradition.

This paper has four aims. The first is to demonstrate how studies in molecular genetics—which explain, at least in part, the mechanism by which evolutionary processes operate—have provided a unified biological codex for all life forms. The major contributions to understanding evolution that have emerged by studying molecular genetics have largely been passed over in discussions of Torah and evolution, inasmuch as those discussions typically concentrate on the reliability of the fossil record and the religious problems that it poses vis-à-vis the age of the world and of life forms.[3]

Our second aim is to address ostensible conflicts between molecular genetics and Torah-based ideas. Third, we wish to develop moral applications of molecular genetics—that is, to demonstrate how studying and applying molecular genetics enables humanity to fulfill some of the Torah's imperatives. Finally, we wish to show how themes in molecular genetics reinforce ethical and religious principles.[4] Human beings are a special creation of God; but we submit that genetic principles provide a direction for pursuing medical treatment and research, conducting studies of human behavior, and achieving justice. They also reinforce humility, instill a sense of individuality and of community, and clarify the nature of faith.

The Modern Theory of Evolution

It is important to understand from a scientific perspective the reciprocal impact of molecular genetics on evolution. In brief, the modern theory of evolution is an attempt to explain the origins of life by stipulating that primitive life forms evolved into the present day diversity of living species. Biological evolution operates at two major levels. The first is micro-evolution, or small-scale evolution, which characterizes genetic changes within one species from one generation to the next. The second is macro-evolution or large-scale evolution, which accounts for one species evolving or transforming into another species.

Conventional wisdom claimed that evolution operates only by natural selection, a process by which individual organisms with favorable traits were more likely to survive and reproduce. However, discoveries in genetics allow us to understand how the process of evolution operates at the DNA level. Currently, scientists assert that all of the following processes, operating independently or simultaneously, can account for

both micro- and macro-evolution: a) mutations, b) selection, c) genetic drift, and d) migration.[5]

a) Mutations and alterations within DNA are major forces driving evolution. Unlike Darwin's original theory of evolution, the modern theory of evolution, called the Modern Synthesis,[6] relies heavily on genetic evidence and molecular biology, connecting these to processes identified by Darwin. All behavioral and physical characteristics that an organism acquired during evolution are highly influenced by genes (coding regions of DNA) and other regulatory, non-coding, genetic elements found in the DNA. DNA alterations or mutations constitute the raw material for developing new biological functions and allow the transmission of these changes to the next generation.

In human beings, differences in eye color, height, body structure, sexuality, behavior, and intelligence, are all reflected in large measure by variations and changes in DNA sequences that have occurred over hundreds or thousands of human generations. According to evolutionary theory and modern scientific data, these DNA mutations occur as spontaneous or random events that can be influenced, but not necessarily determined, by environmental factors such as environment-based radiation, chemicals, or viruses. In addition, behavior and intelligence are highly impacted upon by nurture as well as genetics. (At least in behavior, free choice is a factor as well.)

b) Darwin claimed that natural selection is a dynamic force in evolution when he described how an organism adapts to the selective demands of its environment through successive generations. Today, theories of natural selection or "survival of the fittest"[7] propose that the genetic differences within a species offer survival or health benefits to that species. For example, a specific mutation in chromosome 17 affects a woman's fertility. Females with this genetic variant (called H2 carriers) have significantly more children than females without this genetic variant.[8] Thus, women with the H2 genetic variant would have more children than other women and would be more likely to pass their unique genes to subsequent generations. Interestingly, Ramban alludes to the process of natural selection. In his commentary to Num. 13:32, he states that *Erez̤ Yisrael* was a land that was "*okhelet yoshevehah*" *(*"consumes its inhabitants") because the environment was so harsh that only big and strong people were able to survive. In this manner, the natural environment of the land helped select a race of physically superior people.

c) Genetic drift is a change in the gene pool of a small population that takes place strictly by chance. Genetic drift can result in genetic

traits being lost from a population or becoming widespread in a population without respect to the survival or reproductive value of the alleles involved. Because human beings have only a small number of offspring, not all of the parents' genes will necessarily be passed on to their progeny. In contrast, species that have many offspring tend to distribute all of the parents' genes to various progeny of the next generation. Thus, a small surviving population is going to be affected more dramatically by natural disasters (such as earthquakes, floods, volcanoes, or fires) or by war and may not be representative of the original population in its genetic makeup. Genetic drift differs from natural selection by impacting upon regions of DNA that have no apparent positive or negative impact on reproductive fitness and survival. In contrast, natural selection exerts an impact upon regions of DNA that potentially benefit the survival of a species. Genetic drift can lead to a genetic bottleneck when a significant percentage of a population or species is killed or otherwise prevented from reproducing. Genetic bottlenecks in the Ashkenazi population are thought to account for the current increase in a variety of genetic diseases.

d) The final major process of evolution is migration**;** this accounts for the possibility that individuals from two genetically different populations may interbreed. For example, a population of individuals who have an increased susceptibility for a specific genetic recessive disease like Tay-Sachs might decide to intermarry with a population of individuals who do not carry the genetic mutation for Tay-Sachs disease. Since Tay-Sachs is recessive, the children of this intermarried group would be less likely to express Tay-Sachs.

The Molecular Genetics Revolution

Studies in molecular genetics support evolutionary theory in two ways. First, these studies demonstrate the remarkable similarity between the biological properties of DNA, genes, and chromosomes across numerous species. Second, it is clear now that the plasticity or mutability of DNA not only can regulate evolutionary processes but also operates in our daily lives, protecting human beings from infections but unfortunately at times causing disease.

That DNA regulates micro-evolution is easy to prove experimentally. Bacteria that are normally killed by penicillin can either spontaneously mutate or can be irradiated with ultra-violet light in the laboratory to randomly change the chemical sequence of their DNA, transforming a

small percentage of them into a new strain of bacteria that is now resistant to penicillin. This new strain of bacteria is genetically different from the original penicillin-sensitive parent bacteria and will now produce progeny that can continue to be resistant to penicillin.

The capacity of each individual to mount an antibody response to a pathogen represents human evolution in miniature. Every time a person is infected with a virus or bacteria, successive rounds of random mutations, which never follow a repetitive pattern, occur in the specific regions of DNA within antibody producing cells. These random DNA mutations allow the body's immune system to select a population of cells that specifically synthesizes the correct antibody profile to combat the specific infection.[9] The capacity of these antibody producing cells to mutate is remarkable, due in part to their expression of a unique error-prone DNA enzyme that facilitates their capacity to mutate.[10] Mutations in the DNA of most other cells of the body are rare events, as cells possess multiple mechanisms to proofread and correct errors in the three billion-letter code of human DNA. In fact, current evidence suggests that, on average, only about one un-repaired error occurs in every one billion letters of DNA in most cells of the body, and many of these unrepaired errors or mutations will have no effect on the health of an individual.[11]

There are times when random DNA mutations can translate into human disease. One reason that cancer patients fail to be cured by chemotherapy is that the cancer cells mutate their DNA in response to these drugs. As cancer cells become resistant to the chemotherapy, they will repopulate, re-form tumors, and/or metastasize. The descendants of these cancer cells themselves may also acquire the ability to migrate to new locations, thereby departing from the confines of their tissue origins. The end result is a metastatic form of cancer that is more drug resistant. Untreated, and barring spontaneous remission, unrestrained cellular proliferation typically brings about the failure of critical organ systems and death. Thus, the ongoing capacity of cells to mutate their DNA can also lead to disease and death.

While the above-mentioned mechanisms are thought to drive both micro- and macro-evolution, the evolution of one species from another is more difficult to mimic in the laboratory. Scientists are currently unable to mutate the DNA of an organism of one animal species and transform it into another established reproducing species that possesses a different chromosome number from the original parent.[12] Yet, many leading scientists believe that the underlying aspects of molecular genetics (e.g., DNA mutations, the similarities found in the genomes of all living organisms,

and the fact that the development of complex biochemical systems can be traced from simpler life forms to more complex systems) provide convincing models of how one species could have emerged from another.

Apparent Conflicts Between Molecular Genetics and Torah

Evolutionary biology, including the genetic analysis of life forms, supports the theory that life is four to five billion years old and that living organisms originally developed from a primitive single cell that transformed, via random DNA mutations and other processes (for example, recombination of DNA sequence), into the astonishing tapestry of biological diversity that thrives on the earth today. Evolutionary theory also asserts that all mutations responsible for intraspecies (micro-evolution) or interspecies (macro-evolution) changes occurred randomly in a manner that resulted in both successful and failed genetic variations. These basic aspects of evolution raise potential conflicts because the literal interpretation of Genesis 1-2 entails that each species was created separately and distinctively. (The theological issues regarding the age of the universe and its life forms has been reviewed in other works.[13]) In addition, evolutionary theory asserts that human beings developed from lower animals through a series of merely accidental or random events. How can one reconcile the Jewish belief in an active, personal God while simultaneously accepting the plethora of evidence of randomness in physics, chemistry and biology?[14]

There is no denying the genetic similarities between human beings and other life forms. Most human genes express impressive homology (sequence identity or sequence similarity) to genes found in lower organisms such as worms and mice. In fact, the chimpanzee genome differs from the human genome by only 1% of the three-billion nucleotide bases that encode human DNA.[15] But this does not conflict with the Genesis account. We may simply say that God, the architect of the world,[16] in some way used the molecular biology of DNA as His blueprint in planning the physiological design of all His creatures.[17] Does this mean that God created each species separately using a unified DNA codex, or did God allow speciation to occur by natural processes as proposed by evolutionary theory? Some rabbinical authorities would insist upon the former theory while others would be willing to embrace and maybe even insist upon the latter.[18] But for purposes of what follows, the question is moot. What is critical for us is the unified DNA codex and not necessarily how species came to be. For lessons or themes that can be

derived from these similarities do not depend on which model of the origin of species is adopted.

Of course, from a religious perspective, human beings are a unique species specially created by God. Genetic similarities between human beings and other life forms have not revealed any evidence for an evolutionary development of the soul. Spiritual characteristics that reflect the Torah's understanding of the human soul are not seen in other animals.[19] If one accepts the evolutionary theory of life, then Adam could have physically evolved from lower creatures, but he became a unique being once God endowed him with a divine soul.[20]

The Theology of Randomness

Authoritative sources state that God operates extensively in the universe. R. Ḥanina (*Ḥullin* 7b) teaches that no one bruises his finger on earth unless it was decreed against him in Heaven.[21] A *midrash* states that a snake never bites, a lion never rends, and a government never interferes unless so ordered from above.[22] These references in Ḥazal suggest that God exerts intimate control over all details of our lives and of all creatures and that His control is influenced by our observance of *miẓvot.*[23]

Ramban states that God's knowledge, synonymous with His providence in the lower world, guards the species of His creation.[24] Yet, according to him, the lives of most individual human beings are subject to circumstantial and random occurrences, by which we mean, in this context, occurrences caused by the operation of divinely ordained natural laws and not by specific divine intervention.[25] In contrast, random events (here, *teva*) do not occur to exceptionally righteous individuals; God directs His providence to oversee even the minor details of the *ẓaddik*'s life.[26] For Rambam as well, the degree of providence extended to an individual will increase in proportion to his superiority in the perfection of key human qualities.[27]

In several places, Neẓiv puts forward a complex doctrine about the place of randomness (again, we mean divinely ordained natural law) in the universe. He explains that God created a world governed by a natural order. The appellation *Elokim* is used to denote the divine creator of the laws of nature, which function without God's moment-to-moment supervision—*hashgaḥah peratit*. R. Avahu in *Gen. Rabbah* 9:2 teaches that in creating, God decided "these (processes) please me (as a world fit for humankind's existence) and these do not." However, the name "Hashem Elokim" connotes that God, who ordained the laws of nature, established a relationship with humanity.

Neẓiv maintains that from the time humanity turned to idolatry until Abraham arrived on the scene, the world was ruled by God's natural law. Events affecting humankind occurred without God's active involvement—with two exceptions, the great flood and the Tower of Babel. Writing in connection with the Tower of Babel, he states ". . . the [rest of the] world did not function with *hashgaḥah peratit*— for it is not in accordance with God's honor to involve Himself with such ordinary people…"[28] Neẓiv affirms that, prior to Abraham, randomness existed in all areas except when it impacted upon humankind as a whole and threatened the divine plan for the world. However, Abraham brought God "down to earth" to govern humankind with *hashgaḥah peratit* and thus altered the relationship between God and humankind such that *hashgaḥah* became a force in the world.[29]

There is another important element, however, in Neẓiv's approach to *hashgaḥah.* In the priestly blessing, the *Kohanim* say "May God shine His face upon you" (Num. 6:25), that is, may we enjoy a revealed divine protection from the dangers that plague the survival of all biotic creatures. The absence of God's personal protection is referred to as "*hester panim*" or the hiding of His face. When God hides His face, man is not privy to His providential operations.[30] *Shir ha-Shirim* 2:9 (when construed of course traditionally, as metaphor), further describes God concealing his control over natural events (". . . He is standing behind our wall, looking in through the windows, peering through the lattices."). What appears to a human observer as random may indeed be part of the concealed divine scheme. Like the mother who allows the child to play alone in the backyard yet vigilantly peers through the curtains to ensure the safety of her child, God exerts control in an invisible manner.

In short, randomness is not a synonym for atheism and need not conflict with a Torah-based outlook.[31] When evidence of randomness is used to deny the existence of a supreme being, we have a *non sequitur* that rests on a simplistic understanding of theology, the persistence of which may reflect an antecedent personal belief or bias.

Moral Applications of Molecular Genetics

Medical Treatment and Research

There are many biomedical benefits that emerge from both understanding the genetic similarities between human beings and other organisms and studying the genetic elements that emerge from evolutionary biology. The remarkable similarity in DNA sequences between the human

genome and many other organisms affords human beings an unprecedented opportunity to understand how the body functions in both health and disease. The genetic similarities and differences between humans and other life forms provides a springboard to engage in research that can better the world by improving human health and conquering disease. Such investigations are a critical obligation of human beings. They are included in the *mizvah* of ve-*nishmartem me'od le-nafshoteikhem* (taking vigilant care of our health; Deut. 4:15) and in R. Joseph B. Soloveitchik's understanding of "ve-kivshuhah" in Genesis 1:28. According to R. Soloveitchik, we are to conquer and master nature for the sake of improving human welfare.[32] These mandates challenge Jews to examine the potential of any new technology or scientific principle. Translational biology as described in the new roadmap of the National Institutes of Health challenges scientists to generate practical applications of their basic scientific research in the form of new therapeutics and diagnostic technologies.

The fact that God created human beings as a unique species with biological connections to other organisms, says R. Mordekhai Yosef Leiner of Izbich, is alluded to in the Torah. R. Leiner claims that when God created all various life forms, these creations lacked any means of relating to their Creator.[33] In response to this limitation, the Torah states "And Elokim said: 'Let us make man'" (Gen. 1:26).[34] God used the term "us" to include all previous creations, which were invited to contribute to the creation of man so that man would contain parts of all these creations. This explanation of R. Leiner is consistent with the views of Radak, Malbim, and Ramban[35] that if man would ever be in need of anything, he could find assistance from the other creations of the world. Moreover, when human beings serve God, they elevate and sanctify all the energy received from all the other creations.

Genetic similarities and differences between human beings and animals have enabled medical science to make amazing advances in physiology, pathology, and therapeutics. Almost all drugs approved by the FDA undergo rigorous testing in animals before entering human trials. Scientists studying single-celled organisms, like bacteria and fungi, to more complex organisms, like mice or chimpanzees, have made monumental medical discoveries that directly apply to human beings. It would be irrational to experiment on mice to understand human diseases were it not for the biological and genetic threads that link mice to humans. Furthermore, many leading scientists predict that such genetic comparisons will be instrumental, in the future, in developing new therapies and providing direct benefit to the entire ecosystem.

Despite the genetic and biological similarities between human beings and other life forms, qualitative differences must be recognized. Why are human beings so susceptible to AIDS, coronary heart disease, chronic viral hepatitis, and malarial infections whereas chimpanzees are not? Studying the genetic differences between our species and the chimpanzee through evolutionary biology will help identify those genetic elements that protect chimps from these diseases and render human beings susceptible.

Animal models used for studying disease mechanisms or new therapies that are effective in animals are not always applicable to clinical studies. Indeed, scientists have developed several therapies for curing specific forms of cancer in mice that have failed in clinical trials with human beings. In addition, there are very few animal models that can be used to study human mental illnesses. These biological differences between human beings and other primates were recently highlighted in the failure of a recent drug trial that placed six human subjects in medical crisis.[36] These subjects were given a new drug to treat autoimmune diseases, such as rheumatoid arthritis and type-1 diabetes. Animal studies with monkeys receiving this drug showed no side effects; yet each human subject treated with this drug developed a severe life-threatening medical condition requiring hospitalization. Despite these shortcomings, the intimate genetic relationship between humans and other creatures often enables medical breakthroughs and discoveries.

Unlike conventional biological research that was based on comparing organ function across species, studying and applying the underlying genetic mechanisms of evolution provides novel medical benefits. For example, in 2005, scientists obtained a sample of influenza virus from an infected human corpse frozen in the Alaskan permafrost in 1918. Their research showed how the 1918 influenza virus was initially a virus that only infected birds. A handful of mutations enabled this virus to transform, infect human beings, and kill between 20-50 million people worldwide. Understanding how these genetic mutations changed the biology and infectious properties of the virus will help scientists develop new therapies to treat or prevent future pandemics and outbreaks of influenza or other viruses, such as Avian flu, in human beings.

In sum, were it not for our genetic and biological similarities to other life forms, along with subtle differences between them and us, making medical discoveries would be much more difficult.

Understanding Human Behavior

Although environment and free will obviously are factors in explaining behavior, genes have a major impact. Studying how genes regulate animal behavior can provide important knowledge about human beings as well. It is significant that one of the first activities of Adam after being created was to provide names for all the animals. According to tradition, the specific names that Adam gave to the animals reflected the behavioral characteristics of the animals and provided insights into appropriate and inappropriate human behavior.[37] In *Eruvin* (100b), R. Yoḥanan states that had the Torah not been given, we would have learned various (good) characteristics from different animals. Animal characteristics are also expressed in human beings and should be appropriately studied so that the knowledge gained from such study may be utilized to serve the Creator.

There is also much that can be learned about behavior from similarities and differences in genes that are involved in brain structure and function. There are a variety of genes that are normally highly conserved (that is, there are few changes in the coding sequence of the DNA) within the animal kingdom, but undergo a sudden shift from chimps to humans. FOXP21, a gene involved in speech production, and ASPM2, a gene that affects brain size, have changed in a small but significant manner from the chimp to humans but have profoundly impacted upon the capacity of human beings to speak and think.[38] Examining how these genes differ may lead to a partial but better understanding of how human beings possess a greater intelligence and capacity to reason than chimps and may provide insights into brain pathology and abnormal behavior as well. Thus, understanding our genetic composition can help us understand how to better control our actions.

In summary, while, to repeat, environment and free choice explain much about human behavior, studying the similarities and differences in behavioral genes across species can lead to an enhanced understanding of humans, including an understanding of moral and immoral behaviors.

The Pursuit of Justice

The unique sequence of each person's DNA is the basis upon which DNA evidence is widely used to both convict the guilty and exonerate the innocent. DNA evidence is so accurate that it is tantamount to visual identification and in our view satisfies the need for halakhic identification of the missing (in cases involving potential *agunot*) and of criminal perpetrators. [39]

Religious Principles and Themes in Molecular Genetics

An interesting trend in the ever-growing academic field of "Science and Religion" is the attempt to relate scientific theories to moral and theological values and motifs.[40] For instance, one theologically informed biologist writes "Recent discoveries in biology . . . suggest that we can seek guidance from nature as we articulate religious principles."[41] The effort to derive religious and/or moral principles from nature harks back to the ancient Stoics and runs prominently through later history. Thinkers in this tradition believe that nature is governed by rational and moral principles; from this it follows that we can derive moral lessons from the study of nature. R. Yoḥanan's statement in *Eruvin* 100b that were the Torah not given we would have learned certain good traits from animals, which we cited earlier, illustrates this line of thought. Efforts to find values in scientific accounts are evident in certain rabbinic responses to evolution in the late nineteenth and early twentieth century. The best known example is R. Abraham Isaac ha-Kohen Kook, who, while not consistent in his approaches to evolutionary theory and not necessarily ready to accept it,[42] at points hails the moral and religious implications he sees in the theory, specifically the themes of progress and the interconnectedness of being.[43] To take an example from outside evolution, the clash between geocentric and heliocentric views of the planetary system is associated with the question of the centrality of humans in the divine scheme.[44]

The statement in the Midrash and *Zohar* that "God looked into the Torah and created the universe" (*Gen. Rabbah* 1:1 and *Zohar, Gen.* 134a) suggests, indeed, that nature reflects Torah, and hence that moral lessons can be derived from or reinforced by an analysis of the theory of evolution. To invoke an old idea, God wrote two books—the Bible and the book of Nature. Both must be read; from both we can derive moral and spiritual insight.

We propose three examples that illustrate how specific ideas and themes in molecular genetics reinforce moral and religious values or principles. While consideration of macro-evolution or of similarities between the organs of different species certainly suggests themes like those we will list, we believe that the themes emerge more vividly in the study of molecular genetics, and there attain their fullest expression. Moreover, efforts to link science to moral and religious themes should be formulated at the deepest layers of scientific explanation (in this case the genetics layer). No doubt—and we will spell this out at the end of

this section—the derivation of values from a scientific picture of the world requires a good deal of caution. But the general direction of our analysis boasts numerous antecedents in philosophy and theology.

We turn, now, to our three items.

Humility: The Talmud (*Sanhedrin* 38a) states: "Our Rabbis taught: Adam was created on *erev Shabbat* [as the last creature created]. Why? . . . . So that if man becomes arrogant, one can say to him in reminder: the lowly gnat preceded you in the order of creation of the world!" The remarkable genetic similarities between human beings and animals—the fact that each human being is about 99% genetically similar to the monkey—teaches us that human beings have a propensity to behave like animals if they are not in possession of morals and values that give them true human dignity and enable them to realize their *ẓelem Elokim*.[45]

Individuality and yet community: Many moral systems emphasize both human individuality and an individual's ties to community. Genetic theory provides a singularly vivid way to view ourselves as unique individuals, each of whom—notwithstanding his or her genetic uniqueness, and notwithstanding his or her possessing an individual soul—is also genetically related to family, nation, humanity, and all creation. (Here we have modified a passage in Rav Kook's work.[46]) We believe that the interconnectedness of creation that genetic theory implies dovetails with Rav Kook's emphasis on the unity of all things. This idea raises complex questions about human treatment of other creatures, but an examination of those questions (which Rav Kook undertook) is beyond the scope of this paper.

The theme of genetic individuality is salient in a widespread view in medicine today: that it is the whole genome and not a few genes that influence susceptibility to various diseases and affect medical treatments.

Faith: The element of randomness in DNA mutations and gene expression can at times be difficult to cope with, since these phenomena can lead to devastating diseases, instilling great fear and anxiety. Similarly, when or where God intervenes in human life is not always fathomable and hence His operations appear random—again, an intimidating thought. The Torah provides a fundamental lesson of faith in our lives that applies to the randomness in genetics. Unlike any other species, human beings recognize the unknowability of the future and the randomness of life and death, which could lead to paralysis of action. In order to help us cope with these unknowns, God blessed us with the capacity to have faith to bridge the gap between knowledge and the unknown, so that we can persevere and progress in a world full of random events. With faith, we need not be overwhelmed.[47]

These, then, are moral lessons and themes that committed Jews may derive from the theory of molecular genetics that emerged from evolutionary biology. We make no pretense to having done anything more than point to "rashei perakim." We do hope, however, that future Orthodox thought about evolution will further mine the connections between nature, theology and morality and bring the discussion to the next level. Doing so will give rise to a clearer idea of the interaction between natural facts and ethical principles within a religious framework. Even if the moral principles that are suggested by genetic study are not new or surprising in and of themselves, bringing out the connection between those bottom lines and the natural order is a worthy endeavor. [48]

Although we have indicated that values like humility, individuality, community, and faith are suggested by the natural world as science now conceives it, we wish to make clear that scientific theories are officially value-neutral. Thus, in response to the charge by evolution's opponents that evolution implies racism, eugenics, Nazism, anarchism, and other despicable approaches, it has been argued that facts do not imply values. Evolutionary theory, it is said, describes but does not prescribe; those who pump values out of it are guilty of a fallacy.[49] But from a theistic perspective, unlike a secular one, the order of the divinely created nature reflects values and in particular, we submit, the ones we named—humility, individuality, community, and faith. There are, however, limits to this enterprise: execrable views that grossly violate Torah ethics cannot be "read out of" the laws of nature.[50]

Conclusion

Beyond outlining the science of molecular genetics and its relationship to evolutionary theory, we have sought to exhibit connections between Torah principles and molecular genetics. Studying the field of molecular genetics synthesized with evolutionary biology is worthwhile religiously. The parallel and complementary motifs of Torah and science reflect the statement in the *Zohar*, quoted earlier, that "God looked into the Torah and created the universe."[51] As the supreme genetic engineer, God creates the genetic underpinnings of evolution, which may be applied to fulfill moral imperatives and from which we may derive moral insights or have them reinforced.

Our thesis may be explained by means of a familiar *mishnah* in *Pirkei Avot* (2:2): "yafeh talmud Torah im derekh ereẓ, she-yegiʿat sheneihem mishkaḥat avon." This means, in effect, "worldly knowledge adds beauty

to Torah, for toiling in both areas ensures against sin." We suggest that worldly knowledge can lead not only, as has so often been stressed, to a better theoretical understanding of the universe and greater love of God, but also, perhaps unexpectedly, to the avoidance of sin, the fulfillment of religious imperatives, and the reinforcement of the Torah's moral principles.[52]

Notes

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1. *Hilkhot Teshuvah* 10:6.
2. *Hilkhot Yesodei ha-Torah* 2:2. This view is consistent with the statement of R. Shimon ben Pazi (the statement traces back to bar Kappara) on *Shabbat* 75a. See Moses D. Tendler, "Torah and Science: Constructs and Methodology," *Torah u-Madda Journal* 5(1994): 167-89; repr. in *Mind, Body and Judaism: The Interaction of Jewish Law with Psychology and Biology*, ed. David Shatz and Joel B. Wolowelsky (New York, 2004),17-42. On *Shabbat* 75a, R. Shemuel bar Naḥami provides an additional rationale for scientific study, that such knowledge demonstrates our wisdom to the nations (see Deut. 4:6).
3. As is well known, there are rabbinic figures who oppose evolutionary biology because it seems to negate the literal interpretation of Genesis 1-2. But many of the religious critics have gone further and have sought to refute evolutionary accounts even on scientific grounds. For recent examples, see R. Chaim Keller, "Random Evolution or Intelligent Designer?," *The Jewish Observer* 39 (2006):10-13 (part II of a three-part article); and, in the same issue, the articles by Chaim Presby ("The Third World," 22-26) and Yonoson Rosenblum ("The Myth of Scientific Objectivity," 27-34).
4. Although we cannot fathom God's intentions, it is at least possible that these lessons explain why God incorporated a unified genetic codex throughout the animal and plant kingdom.
5. For an overview, see Sean B. Carroll, Jennifer K. Grenier, and Scott D. Weatherbee, *From DNA to Diversity: Molecular Genetics and the Evolution of Animal Design* (Oxford, 2005).
6. The Modern Synthesis also represents a unification of several branches of biology that previously had little in common, particularly genetics, cytology, systematics, botany, and paleontology.
7. Herbert Spencer, not Darwin, coined the phrase "survival of the fittest." See http://www2.truman.edu/~rgraber/cultev/spencer.html.
8. Hreinn Stefansson, Agnar Helgason, Gudmar Thorleifsson, et al., "A Common Inversion Under Selection in Europeans," *Nature Genetics* 37 (2005): 129–37.

9. For a more detailed description regarding the immune response and antibody production, see Klaus Rajewsky, "Clonal Selection and Learning in the Antibody System," *Nature* 381(1996): 751-58.
10. A. Faili, S. Aoufouchi, S. Weller, F. Vuillier, A. Stary, A. Sarasin, C. A. Reynaud, J. C. Weill, "DNA polymerase eta is involved in hypermutation occurring during immunoglobulin class switch recombination,"*Journal of Experimental Medicine,* 199 (2004): 265-70.
11. See Lynn Helena Caporale, *Darwin in the Genome* (New York, 2002).
12. Scientists are able to generate plants with different chromosome numbers via hybridization and polyploidy technology. See for example, E. W. Rabe and C. H. Haufler, "Incipient polyploid speciation in the maidenhair fern (Adiantum pedatum, adiantaceae)?," *American Journal of Botany* 79 (1992): 701-7 and D. E. Soltis and P. S. Soltis, "Allopolyploid speciation in Tragopogon: Insights from chloroplast DNA," *American Journal of Botany* 76: (1989) 1119-24.
13. For recent discussion, see the references in n. 3, as well as R. Natan Slifkin, *The Challenge of Creation: Judaism's Encounter with Science, Cosmology, and Evolution* (New York, 2006). Authoritative rabbinic sources suggest that the Torah is compatible with evolutionary theory. See, for example, R. Samson Raphael Hirsch, "The Educational Value of Judaism," *Collected Writings*, vol. 7, trans. Gertrude Hirschler (New York, 1992), 264; R. David Ẓvi Hoffman, *Commentary to Genesis*, vol. 1 (Bnei Brak, 1969), 9-52, esp. 9-12; R. Abraham Isaac ha-Kohen Kook, *Iggerot ha-Reayah* (Jerusalem, 1985), I, #91, #134. These and other sources are quoted in Slifkin, *passim,* as well as in materials on his website, zootorah.org. See also Carl Feit, "Modern Orthodoxy and Evolution: The Models of Rabbi J. B. Soloveitchik and Rav Kook," in *Jewish Tradition and the Challenge of Darwinism*, ed. Geoffrey Cantor and Marc Swetlitz (Chicago, 2006), 208-24.
14. For example, genes and exposure to light control only the density of freckles that appear on an individual but the location of these freckles are determined randomly. Analysis of the concept of *mazzal* in Jewish philosophy may have a pronounced impact on how randomness and providence are viewed (manuscript in preparation).
15. Scientists have often pondered how humans possessing 23 pairs of chromosomes could have a common ancestry with other primates that possess 24 pairs of chromosomes. Recent scientific evidence has answered this question by demonstrating that two chromosomes of the monkey appear to have fused into one chromosome, which corresponds to chromosome number 2 in humans. (See http://www.gate.net/~rwms/hum_ape_chrom.html).
16. *Midrash Temurah* 5 (Gen. 1:1) may be the most commonly cited source for the classical argument for Intelligent Design. R. Akiva told his students that "as a house proclaims its builder, a garment its weaver, or a door its carpenter, so does the world proclaim the Holy One, Blessed be He, Who created it."
17. Malbim (Gen. 1:25) points out that the description of creation in the Torah presents an evolutionary-like sequence of events whereby each day introduces a qualitatively higher level of life form.
18. See the references in n. 3 and n. 13.
19. For a subtle and complex account of how man's physicality, which connects him to the rest of existence, is related to his status as an ethical being, see R. Joseph B. Soloveitchik, *The Emergence of Ethical Man*, ed. Michael S. Berger (New York, 2005).

20. R. Yaakov Culi states that "God created man together with the animals to teach him that as far as his body is concerned, he has no advantages over lower animals. His only advantage is his divine soul." See R. Yaakov Culi, *Yalkut me-Am Lo'ez*, trans. Aryeh Kaplan (New York, 1977), I:120.
21. On this *sugya*, see Yaakov Elman, "The Contribution of Rabbinic Thought to a Theology of Misfortune" in *Jewish Perspectives on the Experience of Suffering*, ed. Shalom Carmy (Northvale, NJ, 1999), 186-87. Elman notes that *Ḥullin* 7b includes a statement by Rava that modifies the original statement by Rav Ḥanina, namely, "Only the blood of a second bruising of the right thumb, and only if it happened to one who was about to perform a miẓvah." Otherwise, Rava maintains, there is no indication that the occurrence is an act of divine providence.
22. *Eccl. Rabbah* 10:11. Commentaries state that this refers only to situations where God inflicts punishments upon His people.
23. The concept of *mazzal* is also relevant to this discussion. See *Mo'ed Katan* 28a, where Rava states that "length of life, children and sustenance depend not on merits but on *mazzal*." See also *Shabbat* 156a-b (and various commentaries such as Rashi, Rashba, and Maharsha about the *maḥaloket* as to whether *ein mazzal le-Yisrael* or *yesh mazzal le-Yisrael*). "*Mazzal*" here may mean not chance, but natural law, insofar as Ḥazal accepted *mazzal* as embedded in an astrological system. David Shatz has noted the parallel between medieval astrology and contemporary genetics.
24. Commentary to Gen. 18:19.
25. Ibid. See also commentary to Lev. 26:11 and *Commentary to Job*, in *Kitvei Ramban*, vol. 1, ed. Chaim B. Chavel (Jerusalem, 1963), 108-10 (36:7).

    The decision by God not to intervene is an expression of *reẓon Hashem.* In fact, becoming subject to natural law is a divinely imposed punishment that is referred to by the Torah as *hester panim*.
26. For a development of this interpretation of Ramban's view, along with a discussion of similarities and differences between Rambam and Ramban, see David Berger, "Miracles and the Natural Order in Nahmanides," http://www.zootorah.com/books/MiraclesNahmanides.pdf. This article originally appeared in *Rabbi Moses Nahmanides (Ramban): Explorations in His Religious and Literary Virtuosity*, ed. Isadore Twersky (Cambridge, MA, 1983), 107-28. While divine intervention in the lives of ordinary people is extremely rare for Ramban, it is nonetheless the case that the prayers of such individuals are sometimes answered and that punishments that the Torah promises for specific transgressions, such as death at the hands of Heaven (*mitah bi-yedei Shamayim*), will in fact be forthcoming. See *Torat Hashem Temimah*, in *Kitvei Ramban*, I:153-54 (on prayer) and introduction to *Commentary on Job*, ibid., I:19 (on punishment).
27. Maimonides, *Guide of the Perplexed* 3:18-21. In Rambam's case, the relevant qualities are primarily intellectual. See further Aryeh Carmel, "Freedom, Providence and the Scientific Outlook," in *Challenge: Torah Views on Science and its Problems*, ed. Carmel and Cyril Domb (London and Jerusalem, 1976), 305-44.
28. *Ha'amek Davar*, commentary to Gen. 11:5.
29. Ibid., commentary to Gen. 11:5, 26:1; *Ha'amek She'elah*, vol. 3 (Jerusalem, 1966), *Ekev* 145, pp. 204-05. See also commentary to Gen. 25:21, 18:21. According to Neẓiv, active beneficial *hashgaḥah peratit* (as opposed to passive *hashgaḥah,* leaving people to the vagaries of nature) depends on the

worthiness of the individual. It is not clear how many people actually receive active *hashgaḥah.*

30. The idea of *hester panim* is in the Neẓiv's comment on Num. 6:25.
31. We introduce, however, an important qualification. The sources we cited apply most readily to random events in the lives of individuals and to the realm of micro-evolution. Events in those realms have no bearing on whether the operation of natural law leads to the emergence of human beings. An individual might randomly (i.e., through natural law alone) contract a disease. But if we are speaking of the emergence of new species by these random mutations, the notion that the events necessary to produce human beings were "random" and produced by natural law may not be correct. Still, as we said earlier, we are not dealing in this paper with the origin of species.
32. See *The Lonely Man of Faith* (New York, 1992). See also Ramban's commentary to Gen 1:28.
33. R. Mordekhai Yosef Leiner, *Mei ha-Shiloaḥ*, on Gen. 1:26.
34. The classical interpretation is presented by Rashi: the term "us" reflects God's invitation to the angels to concur in the creation of human beings.
35. See their commentaries to Gen. 1:26. R. Moshe M. Eisemann, *Worlds Beneath the Word: Mining Pirkei Avos for Chinuch Insights* (Lakewood, NJ, 2001), p. 13, maintains that it had originally been the earth's task to produce the animal world*:* "*Toẓei ha-areẓ nefesh ḥayyah le-minah,*" "Let the earth bring forth living beings, each according to its kind" (Gen. 1:24) God was now telling the earth to do for man what it had done for the beasts, except that in this case its contribution was to be only a beginning. The earth was to produce the body as it had done for the whole animal world; God would contribute the soul. See *Avot de-Rabbi Natan* 31:3: "All that God created in His world He created in Man." All features in the natural world find a corresponding feature in human beings.
36. M. Hopkin, "Can Super-antibody Drugs be Tamed?," *Nature* 440 (2006): 855.
37. See Radak, Gen. 2:20 and Menachem Kasher (ed.), *Torah Shelemah* (Jerusalem, 1992), Gen. 2:20.
38. R.S. Hill and C.A. Walsh, "Molecular Insights into Human Brain Evolution," *Nature* 437 (2005): 64–67; Katherine S. Pollard, Sofie R. Salama, et. al., "An RNA Gene Expressed During Cortical Development Evolved Rapidly in Humans," *Nature* 443 (2006): 167-172.
39. Adding the category "pursuit of justice" was suggested by one of the anonymous referees for this paper. For a concise and clear overview of opinions about DNA in areas related to marriage (such as *agunah*), see R. Chaim Jachter's four-part series in *Kol Torah* (a publication of Torah Academy of Bergen County), vol. 1, #18-21. (See http://koltorah.org/index2.html, under "Science and Torah.") This is not the place to respond to those who regard DNA evidence as sometimes or always halakhically inadmissible.
40. See, for example, Ursula Goodenough, "The Religious Dimensions of the Biological Narrative." *Zygon* 29 (1991):603-18; Robert Pollack, *Signs of Life: The Language and Meanings of DNA* (Boston, 1994). We thank David Shatz for suggesting that we situate our ideas in the context outlined in this and the next paragraph.
41. Goodenough, 604. The author is a naturalist, but the quotation nicely typifies the way of thinking we are proposing.
42. See David Shatz, "The Integration of Religion and Culture: Its Scope and

Limits in the Thought of Rav Kook," in *Ḥazon Naḥum: Studies in Jewish Law, Thought and History Presented to Dr. Norman Lamm on the Occasion of His Seventieth Birthday*, ed. Yaakov Elman and Jeffrey S. Gurock (New York, 1997), 545-52.

43. See *Iggerot ha-Reayah* I (Jerusalem, 1985), letters #91, #134; *Orot ha-Kodesh* II (Jerusalem, 1985), 537.
44. See R. Norman Lamm, "Man's Position in the Universe," in *Faith and Doubt: Studies in Traditional Jewish Thought* (third edition, Jersey City, NJ, 2006), ch. IV.
45. This is a recurring theme in the writings of R. Joseph B. Soloveitchik. See, for example, *Family Redeemed: Essays on Family Relationships,* ed. David Shatz and Joel B.Wolowelsky (New York, 2000), esp. 3-104; and *The Emergence of Ethical Man.* It is true that the lesson of humility could be derived from macro-evolution if one believes that species arose naturalistically from other, "lower" species. But if there were special creations by God, the lesson is best learned by reference to genetics or by means of the argument we cited from *Sanhedrin* 38a.
46. See Rav Kook, *Orot ha-Kodesh* (Jerusalem, 1985) 2: 458-59.
47. In truth, science relies on both direct observations and faith. Faith allows human beings to comprehend the beginnings of the universe and the origins of life, without actually understanding the specific details of how the Big Bang actually was initiated or how the genetic codex, embedded in all life forms, emerged from a sea of chemicals. In addition, evolutionary science, like all science, relies on the acquisition of secondary knowledge via a faith-based process. If scientists did not believe their colleagues' reports of observations and experiments, technological progress would be severely hampered since all observations and experiments would require repetition by each scientist. Similarly in religion, human beings cannot visualize how God created the world out of nothing or created the first life form; but faith in our prophets and rabbinic authorities is a cornerstone in Judaism. Thus, both scientists and religious individuals rely on faith to develop their world views and decide on appropriate courses of action.

    One clarification of our argument is needed. If we accept the view of Ramban that all but the exceptionally righteous are subject to divinely ordained natural law ("randomness"), what sense does it make to have faith that it all makes sense? How does our faith help us cope, if we can in fact contract diseases "randomly"? Isn't randomness, on Ramban's view, *in truth* a facet of the universe? By way of reply, we suggest that even on Ramban's approach, a person can have faith that there is a moral order and thereby gain a measure of equanimity. For the people who are subjected to natural law are subject to it because their deeds are not adequate to merit constant active divine protection. Furthermore, as noted earlier (n. 26), prayers of even ordinary individuals are at times answered.
48. Not only are there rabbis who dismiss Darwinian evolution, but several authorities even limit scientific inquiry into creation. Ramban seems to do so in his comments on Moses' statement "consider the days of old, the years of the many generations" (Deut. 32:7). Ramban questions why Moses distinguished between two types of time—"the days of old" and "the years of the many generations." He concludes that the phrase "consider the days of old" refers to the six days of Genesis, while the phrase "years of the many genera-

tions" represents human history beginning after Adam was created. Therefore, according to Ramban, there are two different units of time and the focus of study should be the history of humankind, not creation (see also *Lev. Rabbah* 29:1). The Vilna Ga'on comments on Prov. 25:2 that God's honor demands that we leave hidden what preceded creation and focus only on scientific studies that impact humankind directly. (See *Sefer Mishlei with commentary of the Vilna Ga'on* (Petaḥ Tikvah, 1979), 275.) Sa'adyah Ga'on interprets Eccl. 2:12 as an injunction not to waste time in the study of cosmology, since the truth will never be revealed and little will be accomplished despite the expenditure of great effort. We propose, however, that these authorities would have supported the study of the genetic basis of evolution had they been aware of the benefits to humankind—both medical and moral—that emerge from the molecular genetics of evolution. It should be noted as well that R. Isaiah Horowitz maintains (in interpreting *Ḥagigah* 11a) that it is legitimate to inquire into and examine the processes by which the world was created during the first six days. What will always remain concealed from the human mind, claims R. Horowitz, are matters pertaining to the Ineffable Name inasmuch as it is the name of God's essence. See *Shenei Luḥot ha-Berit ha-Shalem,* ed. Mayer Katz (Brooklyn, NY, 2006), vol. 3, *Terumah,* p. 220.

49. See Philip Kitcher *Abusing Science: The Case Against Creationism* (Cambridge, MA, 1982), ch. 7 (co-authored with Patricia Kitcher).
50. We thank David Shatz for raising the issues discussed in this paragraph.
51. *Zohar* I, 134a.
52. We recognize, of course, that those who deny evolutionary theory see certain moral lessons as reinforced by their literal reading of Gen. 1-2. For example, the miraculous quality of God's creation reinforces belief in the Creator's omnipotence. However, the greater the role one sees for natural law, the more one reinforces belief in divine *wisdom*. We recognize, as well, that some or even all of the lessons we derive from molecular genetics could be derived from a literalist account. But that is the point—the Modern Synthesis supports themes and values that evolution's critics, too, think are important.