The New REPUBLIC

The Great Mutator

by Jerry Coyne

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The Edge of Evolution: The Search for the Limits of Darwinism
By Michael J. Behe
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I.

BROWSING THE websites of different colleges, a prospective biology student finds an unusual statement on the page of the Department of Biological Sciences at Lehigh University. It begins:

> The faculty in the department of biological sciences is committed to the highest standards of scientific integrity and academic function. This commitment carries with it unwavering support for academic freedom and the free exchange of ideas. It also demands the utmost respect for the scientific method, integrity in the conduct of research, and recognition that the validity of any scientific model comes only as a result of rational hypothesis testing, sound experimentation, and findings that can be replicated by others.

So far, so good. After all, every science department should adhere to rigorous canons of research. But then comes a curious disclaimer:

> The department faculty, then, are unequivocal in their support of evolutionary theory, which has its roots in the seminal work of Charles Darwin and has been supported by findings accumulated over 140 years. The sole dissenter from this position, Prof. Michael Behe, is a well-known proponent of "intelligent design." While we respect Prof. Behe's right to express his views, they are his alone and are in no way endorsed by the department. It is our collective position that intelligent design has no basis in science, has not been tested experimentally, and should not be regarded as scientific.

To my knowledge, such a statement is unique. Biology departments do not customarily assert publicly that they support a theory known for more than a century to be true. This is equivalent to a chemistry faculty announcing that "we are unequivocal in our support of atoms." Yet this disclaimer is perfectly understandable. For in this department resides Michael Behe--that *rara avis*, a genuine biologist who is also an advocate of "intelligent design." And Lehigh University does not wish to lose prospective students who bridle at the thought of studying miracles in their science courses.

Intelligent design, or ID, is a modern form of creationism cleverly constructed to

circumvent the many court decisions that have banned, on First Amendment grounds, the teaching of religious views in the science classroom. ID has shed many of the trappings that once cost creationists scientific and legal credibility, including explicit reference to God and the ludicrous idea that the Earth is only about ten thousand years old. Instead, God has been replaced by an unspecified "intelligent designer." Besides making the usual shopworn criticisms of evolutionary theory, IDers contend that some features of life are too complex to have evolved, and so required celestial intervention.

Behe has been an especially valuable ally of the IDers. Not only is he one of the few working scientists in their camp (he is a protein biochemist), thus giving them a smidgen of scientific respectability, but in 1996 he published *Darwin's Black Box*, a popular-science book that has become something of a manifesto for "intelligent design." In that book, Behe updated an old creationist chestnut: the assertion that some aspects of life could not have evolved by means of natural selection, because that evolution would have required untenable steps. Consider the eye, which consists of a number of interacting parts (such as the retina, the optic nerve, the lens, and the cornea) that work together to allow vision. How could such a complex feature have evolved gradually if it could not work unless all its components were already in place? Such features, said Behe, are "irreducibly complex": their evolution supposedly cannot be reduced to a sequential series of adaptive steps, as required by Darwinian natural selection.

Well, scientists already knew that "irreducibly complex" features can indeed be explained by natural selection; and Darwin himself had no trouble doing this for the eye in *On the Origin of Species*, describing a series of perfectly well-adapted living species, each of which had a slightly more advanced version of an eye. Behe's novelty was to extend this argument to complex biochemical pathways, the evolution of many of which we do not yet fully understand. It was in the complexity of metabolism, blood clotting, and immunology that Behe claimed to have found the hand of the Great Designer.

The reviews of *Darwin's Black Box* in the scientific community were uniformly negative, for two reasons. First, we do understand something about how these pathways might have evolved in stepwise fashion, though we are as yet admittedly ignorant of many details. (It is harder to reconstruct the evolution of biochemical pathways than the evolution of organisms themselves, because, unlike organisms, these pathways do not fossilize, and so their evolution must be reconstructed entirely from living species.) Second, in the scientific community a failure to understand something does not automatically count as evidence for divine creation. Science is littered with once-mysterious facts first imputed to God and later found out to be explicable solely through natural processes. This, in fact, is what Darwin's theory of natural selection did to the earlier idea that organisms were designed by a Creator.

More damaging than the scientific criticisms of Behe's work was the review that he got in 2005 from Judge John E. Jones III. After an ID textbook called *Of Pandas and People* was proposed for biology classes at a high school in Dover, Pennsylvania, a group of local parents brought suit against the Dover Area School District and some of its members. There followed a six-week trial in federal court in Harrisburg, Pennsylvania, with the plaintiffs supported by the ACLU and a Pennsylvania law firm, and the school district defended by a right-wing Christian law firm. The case of *Kitzmiller et al.* v. *Dover Area School District et al.*, dubbed

by some "the Scopes trial of our century," included luminaries from both the scientific camp and the ID camp battling it out in front of Judge Jones. With his scientific credentials, Behe was the key witness for the defense.

Jones's 139-page verdict for the plaintiffs was eloquent, strong, and unequivocal, especially coming from a churchgoing Republican. He ruled that "intelligent design" is not only unscientific, but a doctrine based firmly on religion. Jones called the introduction of the clandestinely creationist textbook at Dover High School an act of "breathtaking inanity." He also found Behe's testimony wholly unconvincing, noting that irreducible complexity was not evidence against evolution, and that the biochemical systems touted by Behe were not irreducibly complex anyway. Behe's credibility was damaged also by his admission that ID's definition of science was so loose that it could encompass astrology, and by his fatal assertion that the plausibility of the argument for ID depends upon the extent to which one believes in the existence of God.

But IDers, like all creationists, are never down for the count, because they see themselves as fighting for the Lord. So Behe is back now, with a new book and a brand-new theory that puts the Intelligent Designer back into biology. What has Behe now found to resurrect his campaign for ID? It's rather pathetic, really. Basically, he now admits that almost the entire edifice of evolutionary theory is true: evolution, natural selection, common ancestry. His one novel claim is that the genetic variation that fuels natural selection--mutation--is produced not by random changes in DNA, as evolutionists maintain, but by an Intelligent Designer. That is, he sees God as the Great Mutator.

II.

FOR A START, let us be clear about what Behe now accepts about evolutionary theory. He has no problem with a 4.5-billion-year-old Earth, nor with evolutionary change over time, nor apparently with its ample documentation through the fossil record--the geographical distribution of organisms, the existence of vestigial traits testifying to ancient ancestry, and the finding of fossil "missing links" that show common ancestry among major groups of organisms. Behe admits that most evolution is caused by natural selection, and that all species share common ancestors. He even accepts the one fact that most other IDers would rather die than admit: that humans shared a common ancestor with chimpanzees and other apes.

Why does Behe come clean about all this? The reason is plain. There is simply too much evidence for any scientist to deny these facts without losing all credibility. "Intelligent design" is desperate for scientific respectability, and you do not get that by fighting facts about which everybody agrees. But with most of evolutionary biology accepted, what's left for a good IDer to contest? Behe finds his bugbear in evolutionary theory's view that "random mutation" provides the raw material for evolutionary change. And to understand his critique, we first have to grasp how mutation fits into evolutionary theory, and what scientists mean when they say that mutations are "random."

If evolution is a car, then natural selection is the engine and mutation is the gas.

Although evolutionary change can be driven by several processes, natural selection is almost certainly the main one--and the *only* one that can adapt organisms to their environment, creating the misleading appearance of deliberate design. Yet natural selection, which is simply the preservation of genes that give their possessors greater reproductive success than their competitors, cannot take place without genetic variation. Although Darwin had no idea where this variation came from, we now know that it is produced by mutation--accidental changes in the sequence of DNA that usually occur as copying errors when a molecule replicates during cell division. We also know that mutation-generated variation is pervasive: different forms of genes produced by mutation, for example, explain variation in human eye color, blood types, and much of our--and other species'--variation in height, weight, biochemistry, and innumerable other traits.

Once the variation exists, those genes that enhance an individual's "fitness" are preserved, and those that reduce it are discarded. (Natural selection is not really a "process," but simply a description of the differential and adaptive survival of genes.) The polar bear, for instance, has a white coat (its hairs actually lack pigment but appear white because they reflect light), and since this color is unique among bears, the polar bear presumably evolved from a dark-furred ancestor. The likely scenario is that mutations occurred that produced individuals varying in their coat color. Bears with a lighter coat had an advantage over others, for they would be more camouflaged against the Arctic ice and snow and better at sneaking up on seals. Lighter bears would then outcompete darker ones at getting food and thus produce more offspring, leaving more copies of the "light-coat" genes. Over time, the population of bears would evolve lighter and lighter coats until they were almost invisible against the snow.

ON THE BASIS of much evidence, scientists have concluded that mutations occur randomly. The term "random" here has a specific meaning that is often misunderstood, even by biologists. What we mean is that *mutations occur irrespective of whether they would be useful to the organism*. Mutations are simply errors in DNA replication. Most of them are harmful or neutral, but a few of them can turn out to be useful. And there is no known biological mechanism for jacking up the probability that a mutation will meet the current adaptive needs of the organism. Bears adapting to snowy terrain will not enjoy a higher probability of getting mutations producing lighter coats than will bears inhabiting non-snowy terrain.

What we do *not* mean by "random" is that all genes are equally likely to mutate (some are more mutable than others) or that all mutations are equally likely (some types of DNA change are more common than others). It is more accurate, then, to call mutations "indifferent" rather than "random": the chance of a mutation happening is indifferent to whether it would be helpful or harmful. Evolution by selection, then, is a combination of two steps: a "random" (or indifferent) step--mutation--that generates a panoply of genetic variants, both good and bad (in our example, a variety of new coat colors); and then a deterministic step--natural selection--that orders this variation, keeping the good and winnowing the bad (the retention of light-color genes at the expense of dark-color ones).

It is important to clarify these two steps because of the widespread misconception, promoted by creationists, that in evolution "everything happens by chance."

Creationists equate the chance that evolution could produce a complex organism to the infinitesimal chance that a hurricane could sweep through a junkyard and randomly assemble the junk into a Boeing 747. But this analogy is specious. Evolution is manifestly not a chance process because of the order produced by natural selection--order that can, over vast periods of time, result in complex organisms looking as if they were designed to fit their environment. Humans, the product of non-random natural selection, are the biological equivalent of a 747, and in some ways they are even more complex. The explanation of seeming design by solely materialistic processes was Darwin's greatest achievement, and a major source of discomfort for those holding the view that nature was designed by God.

III.

IN A SERIES of rather disconnected and scientifically dubious arguments, Behe tries to claim that random mutations cannot possibly be the building blocks of evolution. His main argument involves malaria, in particular the evolution of humans to resist infection by malaria, and the evolution of the malaria parasite itself to counteract the evolution of human resistance and the development of anti-malarial drugs.

Malaria actually provides a superb example of natural selection, and its story has some intriguing quirks. The disease is caused by a protozoan carried by mosquitoes, who act as flying syringes that inject the microbe into the human bloodstream. There it takes up residence in the liver and then in the red blood cells, multiplies prolifically, and can ultimately cause anemia, kidney failure, hemorrhage, and death. Residence in red blood cells and the liver is adaptive for the parasites, because in those spots they are hidden from the immune system that usually destroys invading microbes. Yet the human spleen can also detect and destroy circulating parasite-laden cells. To counter this tactic, the malaria parasite secretes proteins that cause its carrier blood cells to stick to the walls of blood vessels, avoiding the spleen (this sticking is what causes hemorrhage).

Here, then, is an arms race between a blood-loving parasite and a human body seeking to destroy it. Yet the story is even more complicated and interesting. In sub-Saharan Africa, where malaria is rampant, a mutation has arisen in the gene producing hemoglobin that helps ward off malaria. The striking thing about this mutation, known as the sickle-cell mutation, is that it somehow reduces the chances of contracting malaria when its carriers have one copy of the gene (like most organisms, we have two copies of every gene, one on each of our two sets of chromosomes), but it causes sickle-cell anemia when the carriers have two copies. In sickle-cell anemia, the red blood cells form clumps because of the altered hemoglobin they carry, causing a syndrome of complications that invariably cause death before adulthood.

Thus we have the unusual situation in which heterozygotes, or individuals carrying both one "normal" and one "mutant" hemoglobin gene, are fitter than homozygous individuals, who carry either two "normal" genes (more susceptible to malaria) or two mutant genes (death from sickle-cell anemia). Evolutionary genetics tells us that in a case such as this one, both forms of the gene will remain in the population, ensuring some protection against malaria but also the continuing production of babies with sickle-cell anemia. Africans would be better off if everyone were a heterozygote, but that is impossible, because the two gene copies separate at reproduction and unite with other copies, necessarily producing some deleterious

homozygotes.

This example shows that natural selection does not necessarily produce absolute perfection; it works with whatever mutations arise to create the best possible situation given the available raw material and the constraints of genetics. And finally, although the malaria parasite has been unable to counter-evolve resistance to heterozygotes for the sickle-cell gene, it has evolved, through mutation, resistance to various anti-malarial drugs devised by humans. This resistance has become so strong that some strains of malaria are completely resistant to drugs--yet another example of successful natural selection.

MALARIA, THEN, shows evolution acting on a number of levels. So how can it disprove Darwinian evolution? According to Behe, malaria shows that random mutation is insufficient to explain biological complexity. He disparages the defensive sickle-cell mutation and similar mutations, saying that they "are quintessentially hurtful mutations because they diminish the functioning of the human body" (does successfully resisting malaria really diminish the function of our body?) and that they are "not in the process of joining to build a complex, interactive biochemical system." And although the parasite and the humans are in the process of trying to outwit each other in an evolutionary arms race (including the development of drugs), Behe notes that this arms race has not prompted the evolution of biological complexity. Instead Behe sees the malaria/parasite battle as a mere "trench war of attrition."

In the end, after pages of rather tedious detail about malaria, Behe dismisses the evolutionary aspects of malaria as "chaotic and tangled," which, while showing random mutation and natural selection, are irrelevant to his main concerns: "In this book we are concerned with how machinery [i.e., complex organisms] can be built," he writes. "To build a complex machine many different pieces have to be brought together and fitted to one another." Behe buttresses his conclusion by describing how the AIDS virus evolved to outwit not only the strategies of the human immune system but also powerful anti-viral drugs. Again he sees little evolution of complexity: "HIV has killed millions of people, fended off the human immune system, and become resistant to whatever drug humanity could throw at it. Yet through all that, there have been no significant basic biochemical changes in the virus at all."

In light of evolutionary theory, these conclusions are truly bizarre. No sane evolutionist has ever claimed that an adaptation of a parasite to a host will produce complex biochemical changes. Evolutionary theory predicts only that parasites *will* adapt, not *how* they will adapt. In fact, both the malaria parasite and the HIV virus have undergone sufficient "biochemical change" to make them almost completely adapted to withstand both human drugs and the immune system. And humans have, through the sickle-cell mutation and other changes in hemoglobin, become somewhat resistant to malaria. Beyond that, what does Behe expect? A red blood cell with hands to throttle the parasite? A malaria parasite with a cunning brain to outwit the sickle-cell protein? HIV and malaria are doing pretty well at reproducing themselves--sans new complex systems--in their present environments. That is all evolution can do.

So what if the malaria parasite has not completely outwitted the sickle-cell mutation? No biologist, least among them Darwin, ever claimed that adaptation is always perfect. Every infection by a parasite, every disease, and every species that goes extinct represents a failure to adapt. Sometimes the right mutations do not arise or cannot arise because of the constraints of development; sometimes they do arise, but produce an imperfect adaptation. In his book *The Causes of Evolution*, the British biologist J.B.S. Haldane addressed this problem with tongue in cheek: "A selector of sufficient knowledge and power might perhaps obtain from the genes at present available in the human species a race combining an average intellect equal to that of Shakespeare with the stature of Carnera. But he could not produce a race of angels. For the moral character or for the wings, he would have to await or produce suitable mutations."

By disparaging the malaria system as mere "trench warfare" and characterizing the mutations involved as "not constructive" and causing "broken genes," Behe not only engages in sophistry, but shows an almost willful misunderstanding of Darwinism. Natural selection is not a one-way path to more complex adaptations or organisms. Organisms adapt to whatever environmental challenges they face, and those changes could require either small biochemical adjustments (as in the case of malaria), more extensive changes that require complex adaptation (as in the evolution of amphibians from fish), or even the evolution of *less* complexity. The tapeworm, for example, is considerably simpler than its ancestor: it has lost its nervous system, its digestive system, and most of its reproductive system, becoming in effect an absorptive sack of gonads. But it is nevertheless well adapted to its novel intestinal niche, where it can dispense with unnecessary features (its food, for one thing, is pre-digested). Using malaria and HIV to argue that random mutations cannot fuel the evolution of complexity is like displaying a crudely built footstool to prove that it is impossible to build a house with lumber, hammer, and nails.

IV.

THE GENERAL READER, at whom *The Edge of Evolution* is aimed, is unlikely to find the scientific holes in its arguments. Behe writes clearly and engagingly, and someone lacking formal training in biochemistry and evolutionary biology may be easily snowed by his rhetoric. The snow falls most heavily when Behe writes about the complex biochemical adaptations of animals, such as the structure and the operation of cilia. Cilia are small, hairlike structures whose rhythmic beating propels microorganisms; they also help move things along in other species (cilia line the fallopian tubes of mammals, for example, where they sweep the egg into the uterus). Each cilium is built from more than two hundred different proteins, including those making up its structure and "motor proteins" that make it move. Moreover, when a cilium is damaged or a new one is built, an equally complex system of intraflagellar transport uses sixteen other proteins to bring new material from out of the cell for repair, rather like a molecular assembly line.

This description is entertaining and instructive, and those unacquainted with molecular biology will be wowed by the elegance of this adaptation. Indeed, such complex features were what lured many of us into biology, hoping to explain their evolution. But the purpose of Behe's exercise, beyond pedagogy, is simply to overwhelm the reader with nature's complexity, hoping to raise the question of how mutation and natural selection could possibly have built such a feature--as if being

wowed were the same as being persuaded. As Behe says, "The point is to see how elegant and interdependent the coherent system is--to see how different it is from the broken genes and desperate measures that random mutation routinely involves." ("Broken genes and desperate measures" refers to the simple adaptations of the malaria parasite and its human opponent.) Surely, says Behe, a better theory is that cilia were created by the Intelligent Designer.

In *Darwin's Black Box*, Behe made exactly the same argument to show that a similar structure, the flagellum (a larger cilium that propels microorganisms), could not have evolved by natural selection. But in this case Behe's claim that no intermediate stages could have existed was refuted. Ken Miller, a biologist at Brown University (and an observant Catholic), showed how flagella and cilia could have had their precursors in mechanisms that the cell uses to transport proteins, mechanisms that are co-opted to construct flagella. Indeed, the whole problem of the evolution of cilia was argued before Judge Jones in Harrisburg, who ruled that there was no convincing evidence that evolution could not have produced this structure, making legal doctrine from something biologists already knew. In his new book, however, Behe simply ignores his critics, repeating his bankrupt claim that there is "no Darwinian explanation for the step-by-step origin of the cilium."

If ID were science, we could make an equivalent demand of its advocates. We could ask Behe to produce a complete step-by-step accounting of what God (sorry, the Intelligent Designer) did when He designed the cilia. And of course Behe would not be able to do that--nor does he even try. IDers never produce their own "scientific" explanation of life. They just carp about evolution. And as evolutionists explain one thing after another, IDers simply ignore these successes and move on to the ever-dwindling set of unsolved problems in which they continue to see the hand of God.

Behe's arguments from the gaps in scientific knowledge are fatuous. It is certainly true that we do not yet understand every step in the origin of the cilium, but these are early days. Molecular biology is a very young field, and molecular evolutionary biology is even younger. The way to understand the evolution of cilia is to get to work in the laboratory, not to throw up our hands and cry "design." Perhaps we will never understand every step in the evolution of a complex feature, just as we cannot know everything about the development of human civilization from archaeology. But is the incompleteness of our knowledge a reason to invoke God? The history of science shows us that patching the gaps in our knowledge with miracles creates a path that leads only to perpetual ignorance.

v.

BEYOND HIS own incredulity, Behe has two other arguments against the efficacy of mutation and natural selection in creating complex features:

> First, *steps*. The more intermediate evolutionary steps that must be climbed to achieve some biological goal without reaping a net benefit, the more unlikely a Darwinian explanation. Second, *coherence*. A telltale signature of planning is the coherent ordering of steps toward a goal. Random mutation, on the other hand, is incoherent; that is, any given evolutionary step taken by a population of organisms is unlikely to be connected to its predecessor.

These arguments betray a profound, almost willful ignorance of the evolutionary process. It is indeed true that natural selection cannot build any feature in which intermediate steps do not confer a net benefit on the organism. As Darwin wrote in *On the Origin of Species*, "If it could be demonstrated that any complex organ existed, which could not possibly have been formed by numerous, successive, slight modifications, my theory would absolutely break down. But I can find out no such case." A century and a half later, there is still no such case. Behe certainly fails to make one.

But he does try gamely, claiming that complex interactions between proteins are features that simply could not have evolved. Proteins represent strings of building blocks--amino acids--and the cooperation between some proteins requires that sets of amino acids in one protein interact rather precisely with sets in another. (For example, the two strings of amino acids making up human hemoglobin, the alpha and beta chains, are closely aligned, and work together in a coordinated way to take aboard oxygen and later relinquish it in the right tissues.) Such precise protein-protein interactions, says Behe, could not have been formed by "numerous, successive, slight steps," because such Darwinian evolution would be wildly improbable.

To demonstrate the improbability, Behe does some math. He calculates the probability that such interactions between amino acids could evolve, assuming that a precise set of amino acids is required. Not surprisingly, it turns out that getting by mutation a set of three to four amino acids required for only one protein-protein interaction is very low (mutations in the DNA affect the building blocks of proteins, since DNA codes for a sequence of amino acids). It is especially low because Behe requires all of the three or four mutations needed to create such an interaction to arise simultaneously. Since any one mutation is very rare (on the order of one in a billion in any given generation at a specified DNA site), the chances that a specified group of changes could arise in one fell swoop is unimaginably rare. And this is for only a single pair of interacting proteins. When you consider the thousands of proteins in a cell that interact with others, some with as many as five or six others, evolution looks impossible.

Wrong. If it looks impossible, this is only because of Behe's bizarre and unrealistic assumption that for a protein-protein interaction to evolve, all mutations must occur simultaneously, because the step-by-step path is not adaptive. Yet Behe furnishes no proof, no convincing argument, that interactions cannot evolve gradually. In fact, interactions between proteins, like any complex interaction, were certainly built up step by mutational step, with each change producing an interaction scrutinized by selection and retained if it enhanced an organism's fitness. This process could have begun with weak protein-protein associations that were beneficial to the organism. These were then strengthened gradually, involving more and more amino acids to make the interaction stronger and more specific. At the end, you get what we see today: many proteins interacting strongly and specifically. What seems improbable in a single leap becomes much more likely when it evolves gradually, step by step.

A simple example shows this difference. Suppose a complex adaptation involves twenty parts, represented by twenty dice, each one showing a six. The adaptation is fueled by random mutation, represented by throwing the dice. Behe's way of getting this adaptation requires you to roll all twenty dice simultaneously, waiting until they all come up six (that is, all successful mutations must happen together). The probability of getting this outcome is very low; in fact, if you tossed the dice once

per second, it would take about a hundred million years to get the right outcome. But now let us build the adaptation step by step, as evolutionary theory dictates. You start by rolling the first die, and keep rolling it until a six comes up. When it does, you keep that die (a successful first step in the adaptation) and move on to the next one. You toss the second die until it comes up six (the second step), and so on until all twenty dice show a six. On average, this would take about a hundred and twenty rolls, or a total of two minutes at one roll per second. This sequential way of getting twenty sixes is infinitely faster than Behe's method. And this is the way natural selection and mutation really work, not by the ludicrous scenario presented by Behe.

As for Behe's assertion that mutation and selection cannot produce "coherence," it is absurd. Coherence is precisely the product of natural selection working with mutation. Yes, mutations are random in the sense I have described, but to say that an evolutionary step taken by an organism is unconnected to its predecessor completely ignores the fact that during evolution organisms are adapting to something in their environment, and that this adaptation can involve a coherent, coordinated response of many features. Consider the evolution of whales from terrestrial animals, now documented by a superb fossil record. The fossils show a wolf-like creature gradually becoming aquatic, with the hind limbs being reduced and finally lost, the forelimbs transformed into flippers, and the nostrils gradually moving atop the head to form the blowhole. How can anyone say that these changes (which of course look planned at the end) are unconnected or incoherent? They represent a case of natural selection eventually turning a land animal into a well-adapted aquatic one.

Not surprisingly, Behe ignores the fact the evolutionists have indeed determined whether mutations are random. Instead, he asserts that randomness is simply assumed by biologists because "the dominant theory [evolution] requires it." That is, all evolutionists are dupes. But for several decades molecular biologists have tested in the laboratory Behe's assumption of non-randomness: that the probability of a mutation being useful increases when a species is exposed to a new environment. These experiments have all failed. As far as we can see, mutations really are random with respect to the "needs" of the organism. There is no reason to assume otherwise.

To get an idea of the power of truly random mutations coupled with selection, we need only look at the successes of animal and plant breeders over the past few centuries. In that time, they have turned the wolf into breeds as diverse as the greyhound, the dachshund, and the chihuahua, and the wild mustard into cabbage, broccoli, cauliflower, and brussels sprouts. Virtually every fruit, vegetable, and meat that we eat has been drastically remodeled by the artificial selection of wild ancestors. All these changes have been immeasurably faster than evolution in the wild, which takes hundreds of thousands to millions of years. And all of these changes have involved selection of random mutations. After all, commercial corn, greyhounds, tomatoes, and turkeys were redesigned by humans, not the Intelligent Designer, and since humans cannot produce miracle mutations, we are limited to selecting whichever ones arise--that is, random ones. To think otherwise would require the extraordinary assumption that the Designer foresaw the intentions of breeders and supplied them with the appropriate miraculous mutations. The success of animal and plant breeding, far outstripping the pace of evolution in nature, is a severe rebuke to Behe's view that evolution cannot work unless God helps it along by producing nonrandom mutations.

VI.

AS THE philosopher Philip Kitcher shows in his superb new book, *Living With Darwin*, the theory of intelligent design is a mixture of "dead science" and non-science. That is, insofar as ID makes scientific claims (for example, that natural selection cannot produce complexity), those claims not only are wrong, but were proved wrong years ago. And ID is deeply unscientific in its assertion that certain aspects of evolution (mutation, in Behe's case) required supernatural intervention. Behe's attacks on evolutionary theory are once again wrongheaded, but the intellectual situation grows far worse when we see what theory he offers in its place.

The first problem is that Behe's "scientific" ideas are offered to the public in a trade book, and have never gone through the usual process of vetting in peer-reviewed scientific journals. This was also the case with *Darwin's Black Box*. In fact, Behe has never published a paper supporting intelligent design in any scientific journal, despite his assertion in *Darwin's Black Box* that his own discovery of biochemical design "must be ranked as one of the greatest achievements in the history of science," rivaling "those of Newton and Einstein, Lavoisier and Schrödinger, Pasteur, and Darwin." Surely such an important theory deserves a place in the scientific literature! But the reason for the lack of peer review is obvious: Behe's ideas would never pass muster among scientists, despite the fact that anybody who really could disprove Darwinism would win great renown.

So let us put some empirical questions to Behe, since his theory is supposedly scientific. Which features of life were designed, as opposed to evolved? How exactly did the mutations responsible for design come about? Who was the Designer? To what end did the Designer work? If the goal was perfection, why are some features of life (such as our appendix or prostate gland) palpably imperfect?

IN RESPONSE to the question of what exactly was designed, Behe's answer seems to be: pretty much everything, including cells, biochemical systems, and the features distinguishing major groups of organisms, such as wings and warm-bloodedness. Behe's criterion is basically twofold: a feature of life must have been designed if it consists of a "purposeful arrangement of parts" and is composed of at least three parts.

But when we see something that looks designed, how do we know whether that design is "purposeful"? Natural selection displaced divine design precisely because it offered a naturalistic explanation for things that appeared to be purposeful. And why three components? This appears to come from Behe's claim that three amino acids are unlikely to change simultaneously in a protein. Well, that claim is true, but it has nothing to do with protein evolution, much less with the evolution of complex features. As we know from the fossil record, the multiple features of organisms that make them look designed--say, the feathers, legs, and wings of birds--did not appear instantly and simultaneously, but evolved gradually. There is not the slightest connection between the likelihood of three binding sites appearing simultaneously in a protein and the likelihood of three features of an organism evolving. Conflating these issues, and hoping that the reader will not notice, must be a deliberate rhetorical trick on Behe's part, for surely even he is not that ignorant

of basic biology.

How did the non-random mutations come about? Well, they were obviously created by the Intelligent Designer. In *Darwin's Black Box*, Behe made the outrageous claim that the Designer might have engineered the first cell to contain *all* the mutations for the evolution of every species that would ever exist. This claim is manifestly false: such a cell would have unmanageably large amounts of DNA, and we see no evidence of "future DNA reserves" in primitive organisms such as bacteria. Behe still raises this possibility in his new book, but he also floats another idea: that mutations might not have been built into the first organism but could have occurred later, foreseen by God. In other words, they were miracles. So you can choose between the two possibilities: either mutations occurred in one big miracle or in millions of little miracles. The first claim is religious and false. The second claim is religious and untestable. Neither claim is scientific.

WHO, PRECISELY, was the Designer? Here Behe weasels a bit, as he should given the federal judiciary's dislike of religion in the science classroom. He mentions that the Christian God is only one of several possibilities. But you can bet that it was not Brahma, or the Bushmen's Kaang, or a space alien. As Jones remarked in *Kitzmiller* v. *Dover*: "Consider, to illustrate, that Professor Behe remarkably and unmistakably claims that the *plausibility of the argument for ID depends upon the extent to which one believes in the existence of God*." It is disingenuous of IDers to pretend that the Great Designer is unknown. Intelligent design has deep roots in fundamentalist Christianity, and its advocates are not fooling anyone.

And what were the Designer's goals? This is where Behe really gives away the game. He asserts that the goal was "intelligent life." Of course, what he really means is humans, presumably because Christians (Behe is a Catholic) feel that humans were made in the image of God: "What we sense, as elaborated through modern science's instruments and our reasoning, is that we live in a universe fine-tuned for intelligent life." And elsewhere: "Parts were moving into place over geological time for the subsequent, purposeful, planned emergence of intelligent life."

From God's mouth to Behe's ear! At this point we can simply stop asking whether Behe's theory is scientific, for he provides not the slightest evidence that evolution had *any* goal, much less one of intelligent life. In fact, every form of life on Earth, from humans to ferns to squirrels, can trace its ancestry back to the same single species that lived about three and a half billion years ago. In that sense, all species are equally evolved and equally removed in time from life's origin. Science long ago dispensed with the notion of the *scala natura*: a progressive ladder of life with humans at the top. Rather, each existing species is at the tip of a branch on the tree of life. So what scientific reason can there be for singling out just one species as the Designer's goal? How do we know that the goal was not butterflies or sunflowers? Plainly, Behe is adopting religious dogma as part of his theory. Yet he continues to assert that "I regard design as a completely scientific conclusion."

And what about the features of organisms that do not look well designed, such as the appendix, the vestigial wings of the kiwi bird, or the vestigial pelvis of whales?

In *Darwin's Black Box*, Behe punted and said that the Designer's goals were unknowable: "Features that strike us as odd in a design might have been placed there by the designer for a reason--for artistic reasons, for variety, to show off, for some as-yet-undetected practical purpose, or for some unguessable reason--or they might not." But if we do not know why the Designer did things, how can we possibly know that his goal was intelligent life?

FINALLY BEHE gets to theodicy: why is there pain and evil in the world if the Designer is omnipotent? How come He/She/It allows innocent babies to get sickle-cell anemia? Behe's answer is that "maybe the Designer *isn't* all that beneficent or omnipotent. Science can't answer questions like that." But questions about the goals, the powers, and the limitations of the Designer are precisely what must be answered if ID is to become scientific. After all, we do know something about the power and the limitations of natural selection, a process that can explain pain and things that seem evil.

Is Behe's theory testable? Well, not really, since it consists not of positive assertions, but of criticisms of evolutionary theory and solemn declarations that it is powerless to explain complexity. And it is certainly true that scientists will never be able to give Darwinian explanations for the evolution of everything. The origins of many features, such as the bony plates on the back of the Stegosaurus, are lost in the irrecoverable past. But neither can archaeology unearth everything about ancient history. We do not maintain on these grounds that archaeology is not a science.

Behe waffles when confronted with the testability problem of ID and turns it back on evolutionists, saying that "coming from Darwinists, both objections [the lack of predictions and the untestability of ID] are instances of the pot calling the kettle black." He then waffles even more when implying that ID does not even need to be testable: "Both additional demands--for hard-and-fast predictions or for direct evidence of a theory's fundamental principle--are disingenuous. Philosophers have long known that no simple criterion, including prediction, automatically qualifies or disqualifies something as science, and fundamental entities invoked by a theory can remain mysterious for centuries, or indefinitely."

But who is being disingenuous here? Evolution has been tested, and confirmed, many times over. Every time we find an early human fossil dating back several million years, it confirms evolution. Every time a new transitional fossil is found, such as the recently discovered "missing links" between land animals and whales, it confirms evolution. Each time a bacterial strain becomes resistant to an antibiotic, it confirms evolution. And evolutionary biology makes predictions. Here is one that Darwin himself made: that the earliest human ancestors will be found in Africa. (That prediction was confirmed, of course.) Another was made by Neil Shubin at the University of Chicago: that transitional forms between fish and amphibians would be found in 370-million-year-old rocks. Sure enough, he discovered that there were rocks of that age in Canada, went and looked at them, and found the right fossils. Intelligent design, in contrast, makes no predictions. It is infinitely malleable in the face of counterevidence, cannot be refuted, and is therefore not science.

IN THE END, *The Edge of Evolution* is not an advance or a refinement of the theory of intelligent design, but a retreat from its original claims--an act of desperation designed to maintain credibility in a world of scientific progress. But it is all for nothing, because Behe's new theory remains the same old mixture of dead science and thinly disguised theology. There is no evidence for his main claim of non-random mutation, and scientists have plenty of evidence against it. His arguments against the Darwinian evolution of complex organisms are flawed and misleading. And there is not a shred of evidence supporting his claim that the goal of evolution is intelligent life. In contrast to the feast of evidence that nourishes evolutionary theory, Behe gives us an empty plate.

The overweening strategy of IDers, and their creationist forebears, is to say that everything that we do not understand is evidence of the existence of God. I can imagine IDers of two centuries ago claiming that God made the sun shine, because until 1938 we had no idea where all that energy came from. It was not until quantum mechanics arrived out of left field that the physicist Hans Bethe was able to surmise, correctly, that the sun is a giant fusion reactor, converting hydrogen atoms into helium and energy. Who knew?

One of the great joys of science is that we never know what will happen next. Who could have guessed twenty years ago that dinosaurs probably became extinct after a giant meteorite collided with Earth and produced a "nuclear winter"? IDers would deprive us of this essential excitement, urging us to stop working when we come up against the hard problems and to ascribe our difficulties to God. They would have us join the herd of the benighted who proclaim so confidently that they have descried the bounds of our knowledge. But this attitude, this philosophy, was anticipated and unmasked by none other than Darwin himself, who was prescient not only about biology, but also about the nature of science: "Ignorance more frequently begets confidence than does knowledge: it is those who know little, and not those who know much, who so positively assert that this or that problem will never be solved by science."

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