5

# The Argument from Biological Complexity

Michael J. Behe

## 1. Philosophical aspects of the argument

### 1.a. General characteristics

This chapter argues that advances in our understanding of the molecular level of life overwhelmingly support the conclusion that, to a very large degree, life is the intended product of a designing mind. Several general characteristics of the design argument will be noted here at the outset.

The first characteristic to note is that the argument for design from biochemistry is in large part an empirical argument. That is, it depends critically on our detailed understanding of the physical structures and processes of life. In turn, that means it depends on the progress of science in elucidating those structures and processes, and that the persuasiveness of the argument can shift with empirical discoveries. Such discoveries have been made since Darwin first put forward his theory.

It has been only since the middle of the twentieth century—a hundred years after Darwin's work, when the double helical structure of DNA and the irregular functional shape of the oxygen-binding protein myoglobin were discovered—that biology has begun to grasp the mechanisms of the molecular foundation of life. Over the past seventy years progress has accelerated enormously with the development of powerful new laboratory tools. An overarching discovery is that the foundational level of life is run by astoundingly complex molecular machinery. That key breakthrough drives much of the argument here. Furthermore, although it is an empirical observation, it is very secure; future work may show life to have greater functional intricacy than we now recognize, but it will not show it to have less.

In addition to empirical data, the argument for design from biochemistry requires logical ties to connect the data to the conclusion. Unlike other writers such as David Hume,[1] who cast the design argument mainly as one from analogy, Steven Meyer,[2] who sees it as an inference to the best explanation, or Elliott Sober,[3] who treats it as a likelihood argument, I consider the design argument to be an inductive one. That is, as we shall see, by considering how we draw conclusions that some inanimate systems were purposely designed, common elements can be extracted to guide us when attempting to decide if some biochemical systems were purposely designed.

The second characteristic of the argument for design from biochemistry to note initially is that, because it is in large part an empirical argument, then much like any good scientific argument it is formally falsifiable[4]—that is, future empirical discoveries may force a revision to, or even overturn, the biochemical design argument. One need not, of course, judge that outcome as probable to acknowledge that all empirical arguments are in principle falsifiable. An important corollary is that the design argument should not be criticized for being what it is—an inductive, empirical argument. Additionally, like any scientific argument, it cannot prove in a logical, deductive sense that all rival explanations are false. Rather, like them, it should be evaluated on how well it fits the empirical evidence.

A related limitation of the biochemical design argument is that it is restricted in scope. It is an argument from *physical evidence* to the conclusion of *design simpliciter*—to the bare conclusion that some physical systems were intentionally arranged. It leaves aside secondary questions for the present, such as: who did the designing? why? how? when? and so on. (In fact, such related questions do not even arise unless we first suspect something to have been designed.) It is not an argument, as is the "Fifth Way" of Thomas Aquinas, from *design* or *teleology* to the conclusion that *God exists*.[5] The biochemical argument gives reasons to think merely that much of life was purposely arranged. I emphasize that, by itself, it cannot be an argument for the existence of God. Even when successful, it only affirms the existence of an agent with the intelligence and ability to design life. It says nothing about other qualities that philosophical arguments have attributed to God, such as self-existence, incorporeality, eternality, benevolence, omniscience, and omnipotence.[6] Although, for some people, the empirical argument for design from biochemistry may increase the persuasiveness of such traditional philosophical arguments, or decrease the persuasiveness of arguments claiming to disprove the existence of God, taken alone it says nothing definitive about God.

### 1.b. Recognizing the work of a mind: a purposeful arrangement of parts

To understand the biochemical design argument, we must first understand how we recognize design in general. Philosophers have long grappled with the question of other minds—that is, how can we know that some other beings have minds?[7] After all, we cannot directly perceive the thoughts of other minds with our senses. For all we know, even other people (who physically resemble us), let alone animals, aliens, or more exotic possibilities, may be "zombies"—entities that behave in much the same way that we do, but have no inner mental life.[8] It's a fascinating, difficult, perhaps even unsolvable problem. But there is a more basic, much more accessible question: why do we even *suspect* that some things may have minds? Many things exist to which we are not tempted to attribute a mind: dirt, rocks, sand, and more. So why do we suspect some other things do in fact have minds? Or that things with minds have acted?

The eighteenth-century Scottish philosopher Thomas Reid pointed out that, although it cannot directly be observed, we infer intelligence—the existence of a mind—through its physical, empirical, observable effects:[9]

Now, every judgment of this kind is just one application of *the design principle*, the general principle that intelligence, wisdom, and other mental qualities in the cause can be inferred from their marks or signs in the effect. The things men say and do are effects, of which the speakers and doers are the causes. We perceive the effects through our senses, but the causes are behind the scene. We simply *infer* their existence and their degrees from what we observe in the effects. From wise conduct we infer wisdom in the cause, and so on.

What are those observable marks of intelligence? The relevant definition of *design* is "the purposeful arrangement of parts."[10] Thus the key is this: *because minds can choose to order for a purpose whatever is within their power to manipulate, intelligence is detected by perceiving a purposeful arrangement of parts*. That is *the* way, the *only* way, that we can discern the existence of other minds and their intelligence. Conversely, whenever we see parts that appear to have been arranged intentionally—arranged for a purpose—we conclude with greater or lesser conviction that a mind is behind the arrangement, either proximately or remotely.

For the goal of detecting intelligence, the word *parts* is construed very broadly, as "something determined in relation to something that includes it"[11]—that is, as any facet contributing to the design. In human speech, we purposefully arrange sounds to form words. In writing, we arrange letters. In constructing machinery, we arrange mechanical or electrical parts. In planning a surprise party, we may arrange not only physical objects such as tables and chairs, and written words to write invitations, but also the very timing of events as well, such as when the invitees are to gather in secret and when the guest-of-honor is to be led under pretense to the party's pre-arranged location. Purpose can also be discerned in coordinated motions and gestures. Sign language is a straightforward example. Another is an organism arranging its muscular activity to move itself, such as a runner headed toward a finish line or an eagle swooping toward the surface of a lake. In all of these various illustrations we recognize a mind behind the arrangements.

Design may occur at multiple independent or hierarchical levels, or between undesigned levels. For example, formulating materials to make ink, arranging ink into letters, letters into words, words into sentences, and sentences into paragraphs are all different levels of design;[12] the higher levels (sentences, paragraphs) make use of the lower ones (ink, letters, words), but go beyond each of them. With machinery, many parts (for example, nuts, bolts, gears and so on) may show their own designs in their specific shapes and other properties; the organization of those designed parts is a separate level of design. For any particular example, there may be no reason to suspect purposeful design at a higher or lower level. The chemicals that go into ink may be undesigned, natural inorganic materials. The paragraph into which some ink is arranged may be found on a crumpled piece of paper in a wastebasket, with no indication that it is part of a larger design such as a book or encyclopedia. Similar arguments can be made for machinery, party planning, or any design.

A critical characteristic of the empirical design argument to grasp is that it is *quantitative*—the more parts there are, and the more closely they are arranged to fit the purpose, the much more confident we can be in a conclusion of design. If Scrabble

letters were spilled onto a table, we would positively expect to observe some letter or letters to be right-side-up by chance. Right-side-up letters near each other that formed a short word might appear in the mix by accident. But as the spilled letters were seen to form a longer word, sentence, or paragraph, our confidence in design would approach certainty. The same progression happens as mechanical parts form an ever more complex machine, or as the closer and closer timing of events permits a surprise party.

The quantitative aspect of the design argument is a reflection of the fact that, as Thomas Reid noted,[13] we judge the degree of intelligence by the difficulty of arranging parts for a particular purpose. Just as longer words formed by spilled Scrabble letters more strongly indicate design, offering wise counsel to a troubled youth demonstrates more wisdom than giving foolish advice; solving a calculus problem shows more intelligence than adding two integers; building a skyscraper shows more than a beehive; and so on. It is necessary to realize, however, that an agent might be more intelligent than its actions show. For example, a person we see adding two integers might also have the ability to do calculus.

The topic of how one determines what the purpose of an arrangement of parts might be deserves much greater consideration than can be given here. The ultimate, or even proximate, intentions of an intelligent agent may be obscure, and that may interfere with our judgments in marginal cases. Nonetheless, in many other cases at least the proximate purpose is plain from the physical arrangement itself. For example, the arrangement of parts that constitutes a camera strongly attests to its purposeful design, even if the ultimate purpose of the designing agent was to, say, become wealthy. Similarly, the arrangement of the parts of an eye betrays its purposeful design, no matter what the ultimate purpose may be. As a rule of thumb, one should look to the proximate purpose of an arrangement of parts when judging its possible design. Fortunately, the molecular machinery discovered in the cell often exhibits very strong proximate purpose in the arrangement of its parts.

### 1.c.  Cleanthes' implicit induction

I consider the argument for design to be an inductive one, not an argument from analogy or likelihood, or as an inference to the best explanation as others do. In an inductive argument, one can reason from multiple particular instances of a phenomenon to a general conclusion. For example, black clothes, black paint, and black rocks all become warmer in sunlight than otherwise-similar white objects; thus it is probable that the next class of black objects will be found to become warmer in sunlight than otherwise-similar white objects. Notice that the particular instances being compared differ from each other in many ways. Yet the induction holds because the conclusion depends only on one shared property—blackness. Therefore to call such an induction into doubt one would have to show that dissimilarities make a relevant difference to the property under consideration. Furthermore, an induction may be greatly strengthened over time by new knowledge. For example, with progress in understanding the physics and chemistry of light absorption by pigments, the reason that black objects become warmer in the sunshine has been placed on

a foundation that is much firmer than that of the simple association with which it began.

Failure to recognize the correct form of a design argument can lead to much confusion. In an analogy, the more attributes that the analogized subjects have in common, the stronger the likelihood they will share an additional characteristic under discussion. In Hume's 1779 classic, *Dialogues Concerning Natural Religion*, which features characters representing different views on natural theology, the skeptical Philo criticizes Cleanthes' argument that the universe is analogous to a human machine and that the analogy demonstrates not only the intelligence but also other attributes of God. Philo objects that the universe strikes him as more like an animal or vegetable than as a machine. In any event, Philo points out, there are many differences between the universe and human artifacts and so the analogy is quite weak. Yet with one example Cleanthes reduces Philo to befuddlement. Cleanthes asks Philo to suppose:[14]

> that an articulate voice were heard in the clouds, much louder and more melodious than any which human art could ever reach; suppose that this voice were extended in the same instant over all nations … [C]ould you possibly hesitate a moment concerning the cause of this voice, and must instantly ascribe it to some design or purpose?

Philo makes no substantive reply; eventually the dialog drifts on to other topics. What is different about this example?

The difference between Cleanthes' successful voice-in-the-clouds example and his unsuccessful other examples is that the case of the voice is an implicit induction, not an analogy. Whenever we have heard articulate voices we have found them to come from intelligent sources (either proximate or remote). Thus if we heard a voice coming from a cloud we would conclude the same. What's more, we have a deeper reason to conclude the involvement of intelligence. We know that an intelligent agent has the ability to manipulate parts for a purpose. We know of no other cause that has that ability. (Hume has Philo briefly present the design argument also as an inductive argument, but as a particularly careless one—that if we wish to show by induction that our world was designed *in toto*, we must have experience of other worlds that were designed *in toto*.)[15]

In the passage quoted above, Cleanthes tries to push his example further than mere design, so we must be careful to distinguish separate, critical aspects of it. Only the articulate voice—that is, the purposeful arrangement of sounds—is needed to demonstrate an intelligent source. The minimum degree of its intelligence is manifest in whatever message it conveys. Cleanthes adds superfluous attributes—the message's loudness and melodic nature—apparently to steer the conversation toward God himself, but neither of those are needed to demonstrate bare intelligence. One detail— that the voice is heard simultaneously in all nations—is intended, it seems to me, both to push the conclusion toward God and to rule out the possibility that just a single person had an auditory hallucination (by indicating that the knowledge is universally shared). But if, instead of an ephemeral voice, one were discussing a persisting physical object such as a manuscript or a machine—which could be examined by multiple people over time—then hallucination is easily ruled out.

Hume wrote in the eighteenth century. If we moderns heard a voice from a cloud we might think it was a broadcast from an airplane or some other technological trick—no need to think otherwise. Yet whether the voice came from God, aliens in a space ship, a human ventriloquist, a radio, a recording, or some technical trick whose details we did not know, like Cleanthes we would certainly "ascribe it to some design or purpose." We would easily recognize the intelligence in the purposefully arranged sounds of the message.

Whether the agent behind the voice were friendly, hostile, or indifferent to us is much more difficult to conclude than whether it is simply intelligent, as is the question of whether the agent is also an omnipotent being responsible for the whole universe. Like others before and after him, Cleanthes ran into trouble by confounding separate issues and trying to claim too much. Design itself is abundantly clear in the empirical observation of a purposeful arrangement of parts. Drawing conclusions beyond mere design requires other kinds of arguments. However, the possible lack of soundness of downstream arguments—concerning who, what, how, why, and so on—does not negate the original conclusion of purposeful design.

With the preceding discussion as background, the inductive biochemical argument for design can be stated as follows:

(1)  We know from experience that intelligent beings can have purposes and that, to achieve a purpose, they can choose to arrange whatever is within their power to manipulate. As a result, the action of an intelligent being can be detected by perceiving a purposeful arrangement of parts.

(2)  Whenever we are familiar with a causal chain that produces a sufficiently complex, purposeful arrangement of inanimate parts, we always find one of the causes to be an intelligent agent, acting either proximately or remotely in the causal chain.

(3)  The molecular basis of life consists of inanimate molecules (such as proteins, polysaccharides, lipids, and nucleic acids). In living beings, these molecules are often found combined in extraordinarily complex, purposeful arrangements.

(4)  Claims of marvelous abilities for Darwinian processes notwithstanding, we know of no unintelligent process that, when examined in sufficient detail, mimics the ability of intelligence to arrange parts for a purpose.

(5)  By (1), (2), (3), and (4) we are justified in concluding that a cause of many complex, functional, molecular aspects of life was an intelligent being, acting either proximately or remotely.

A fundamental difference between living and non-living systems is reproduction and the consequent ability of life to undergo variation and selection. As I will argue in the rest of this chapter and as I've shown at much greater length in previous writings,[16] however, although those factors can affect life marginally they are thoroughly unable to account for the machinery of life. Reproduction, variation, and selection have no ability to arrange parts for a purpose. Therefore, the inductive argument for design applies to both animate and inanimate systems.

## 2. Empirical aspects of the argument

### 2.a. A very brief history

The first part of this chapter discussed the logical underpinnings of the design argument. I now turn to a discussion of the progress of science on relevant empirical topics.

For virtually all of recorded history most people believed nature in general and life in particular to have been purposely designed. For example, in *On the Usefulness of the Parts of the Body*, the Greek pagan Galen—the most eminent physician of the classical era—concluded that the human body is the result of a "supremely intelligent and powerful divine Craftsman," that is, "the result of intelligent design."[17] Fifteen hundred years after Galen, the English clergyman William Paley made the strongest argument for design to that date, incorporating into it much biology that had been unknown to Galen. The very anatomies of the eye, muscles, blood vessels, and more were strong pointers to design, he argued, for the same reason that deducing a pocket-watch found in a field was designed:[18] "For this reason, and for no other, namely, that when we come to inspect the watch, we perceive that its several parts are framed and put together for a purpose . . . [T]he inference we think is inevitable, that the watch must have had a maker." When multiple parts are ordered to each other, and by that arrangement the system acquires the ability to perform a function such as keeping time, then the inference to design is powerfully justified, thought Paley.

Although he admired Paley's work in his youth, as a result of his own discoveries while acting as the ship's naturalist of the HMS *Beagle* Charles Darwin later proposed that a hitherto-unrecognized natural process could mimic a designing intelligence: random variation sifted by natural selection. In brief, Darwin saw that there was variation in each species. Some members of a species might be bigger than others, some faster, some brighter in color. He realized that not all organisms that were born could survive to reproduce, simply because the limited resources of nature would not permit an unlimited expansion of a species' population size. From that Darwin reasoned there would be a struggle for those limited natural resources. A member of a species whose biological variation gave it an edge in the struggle to survive would have an increased chance to leave offspring—that is, natural selection. If the variation could be inherited, then the next generation would be enriched in organisms that carried it, and the next generation even more so, until the variation became the norm. At that point the species as a whole would have changed from what it had been. Many subsequent repetitions of the same process, starting from other random variations, might over long times change a species into something quite different from the ancestral form.

It seemed to be a promising idea. However, Darwin was severely handicapped by the relatively primitive state of biological knowledge of his time. For example, in the mid-nineteenth century physicists and chemists still debated whether molecules were real entities.[19] And the cell, which is now known to be the foundation of life, was then thought to be simple—in the words of Ernst Haeckel, a "simple little lump of albuminous combination of carbon."[20] Thus Darwin and his contemporaries were ignorant of a tacit-yet-key factor of his theory—the nature of heredity.

Scientific progress in the twentieth century revealed that the basis of life occurs at the cellular and molecular levels. Beginning with Watson and Crick's elucidation of the double helical structure of DNA[21] and Kendrew's solving of the structure of myoglobin,[22] research in the second half of the twentieth century showed that the foundation of life is run by large, complex, molecular machines, and that mutations in the machinery were far more likely to damage it than to improve it. Accelerating progress in the twenty-first century in the ability to sequence DNA has allowed scientists to determine the identities of many beneficial mutations. As discussed below, a large majority of those, too, damage, rather than improve, molecular machinery.

## 2.b.  Problems for Darwin's theory

### (i)  *The critical question of randomness*

To properly evaluate the intelligent design argument, it is crucial to distinguish the question of the descent of modern organisms from ancient ancestors from the question of what might have driven that process—what might have caused such fantastic changes to occur? As noted by Ernst Mayr,[23] what is often referred to as a single idea—"Darwin's theory"—is actually an amalgam of a handful of separable ideas: 1) species change with time; 2) the common descent of all organisms (branching evolution); 3) the gradualness of evolution (no saltations, no discontinuities; 4) the multiplication of species (the origin of diversity); 5) natural selection (the directional driver of evolution), which in Darwin's time implicitly included the idea of random variation. Mayr points out that, although most biologists in the decades after the publication of *The Origin of Species* readily accepted the proposal of common descent, they were skeptical of Darwin's proposed mechanism of evolution. That remains the case for many biologists today as modifications and revisions to Darwin's theory continue to be proposed.[24] It is specifically the *Darwinian mechanism* that the argument for design from biochemistry challenges. It does not challenge the proposals of common descent, or gradualness, or other parts of Darwin's theory, but only the role of randomness.

### (ii)  *The major conceptual difficulty for Darwin's theory*

The preeminent conceptual difficulty for Darwin's mechanism as the chief driver for the development of life is its need to account for the gradual evolution of life's intricate, complex, functional systems without intelligent guidance. The Oxford biologist Richard Dawkins explains the need for gradual evolution:[25]

> A key feature of evolution is its gradualness. This is a matter of principle rather than fact . . . Evolution is very possibly not, in actual fact, always gradual. But it must be gradual when it is being used to explain the coming into existence of complicated, apparently designed objects, like eyes. For if it is not gradual in these cases, it ceases to have any explanatory power at all.

Yet many aspects of life certainly do not appear to be amenable to gradual evolutionary construction. Within a decade of the publication of the *Origin of Species* the English

biologist St. George Mivart challenged the theory on the grounds of the "incipient stages of useful structures." Many biological systems, Mivart argued, could not plausibly have been useful to an organism as inchoate structures.[26]

> "Natural Selection," simply and by itself, is potent to explain the maintenance or the further extension and development of favourable variations, which are at once sufficiently considerable to be useful from the first to the individual possessing them. But Natural Selection utterly fails to account for the conservation and development of the minute and rudimentary beginnings, the slight and infinitesimal commencements of structures, however useful those structures may afterwards become.

Although he tried to respond to some of Mivart's examples in later editions of the *Origin*, Darwin's attempts were once again severely hamstrung by a lack of understanding of the molecular and cellular foundation of life. Consider Darwin's oft-cited example of possible evolutionary steps leading to the vertebrate eye, beginning with a light-sensitive spot, proceeding through a pinhole eye, then to an eye with a lens.[27] Yet Darwin had no idea of the many complex molecular structures that underlie any of those structures. As he wrote of the light-sensitive spot, "How a nerve comes to be sensitive to light hardly concerns us more than how life itself originated."[28] Whether or not his hypothetical scheme was workable depended on a multitude of factors that resided at a level of life that was unknown to him.

Related to Mivart's argument about the "incipient stages of useful structures" is the argument of "irreducible complexity," which becomes clearest at the molecular, foundational level of life. I defined *irreducible complexity* in 1996 in *Darwin's Black Box* as "a single system which is composed of several well-matched, interacting parts that contribute to the basic function, and where the removal of any one of the parts causes the system to effectively cease functioning." To illustrate the concept for the general reading public, I pointed to the example of a common mechanical mousetrap consisting of multiple pieces. Each of the five larger pieces (platform, spring, hammer, holding bar, and catch) pictured in Figure 5.1 is needed for the mousetrap to work. There are also several small staples holding the larger pieces together. The correct placement of the staples is also needed for the function of the system. Furthermore, several of the pieces have complex shapes and other properties that are needed for system function. A mechanical mousetrap is a relatively simple machine. By extension, more complex machinery is very likely to be irreducibly complex (IC) as well.

If any IC systems occurred at the molecular level of life, the difficulty they would present to Darwin's mechanism is readily apparent. Natural selection requires some function to exist before it can be selected. Yet for IC systems, the function appears only when the system is complete. Thus the straightforward conclusion is that evolutionary construction of IC systems cannot be guided by a Darwinian mechanism.

Since the introduction of this concept twenty-five years ago, two main lines of response have been offered by Darwinian biologists. First, H. Allen Orr pointed to the writings of the early twentieth-century geneticist H. J. Muller, who wrote that a new feature *B* may be added to an already functioning organ *A*, and over time that new
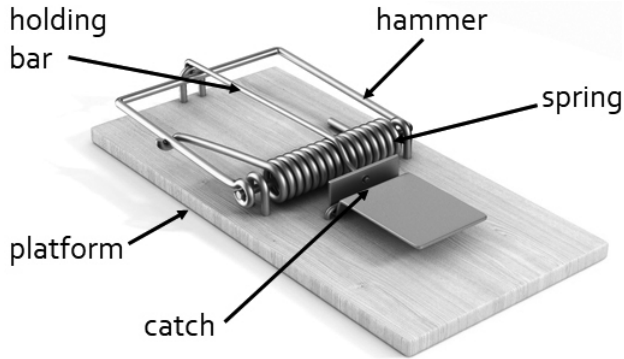
**Figure 5.1**  A mechanical mousetrap with multiple parts (Ilin Sergey/Shutterstock).

feature is integrated so thoroughly that removing it breaks the functions of both *A* and *B*.[29] Thus—although by hypothesis it developed gradually—the combined organ might appear to need both parts *A* and *B*. Unfortunately, as I criticized it, the argument is fatally vague.[30] What *A* and *B* may represent at the molecular level Muller had no way of knowing and Orr does not say. It is quite difficult to see what parts *A* and *B* would correspond to for a mousetrap. As we'll see below, the same difficulty applies for molecular machinery.

The second main line of response by Darwinian biologists to the problem of irreducible complexity is to speculate about indirect routes to complex systems. Brown University biologist Kenneth Miller has argued that parts of a mousetrap might be useful in other roles, for example as a tie clip, paper weight, and so on.[31] However, as H. Allen Orr agreed, indirect routes to a complex structure that switch functions/roles are very unlikely to be successful. As he wrote:[32]

> Second, we might think that some of the parts of an irreducibly complex system evolved step by step for some other purpose and were then recruited wholesale to a new function. But this is also unlikely. You may as well hope that half your car's transmission will suddenly help out in the airbag department. Such things might happen very, very rarely, but they surely do not offer a general solution to irreducible complexity.

Selection on a simple paperweight would not be expected to produce a tie clip, and selection on a tie clip would not be expected to produce a mousetrap. Like the first main line of response, the second one also remains utterly unsupported by experiment.

### *(iii)  The unexpectedly, extraordinarily intricate physical foundation of life*

Beginning in the 1950s with the development of X-ray diffraction techniques for the elucidation of the structures of DNA and proteins, science has steadily

uncovered more and more of the molecular workings of life. Even several decades ago Bruce Alberts, then president of the National Academy of Sciences, could write:[33]

> We have always underestimated cells. Undoubtedly we still do today. But at least we are no longer as naive as we were when I was a graduate student in the 1960s . . . The chemistry that makes life possible is much more elaborate and sophisticated than anything we students had ever considered . . . Indeed, the entire cell can be viewed as a factory that contains an elaborate network of interlocking assembly lines, each of which is composed of a set of large protein machines. Why do we call the large protein assemblies that underlie cell function protein machines? Precisely because, like the machines invented by humans to deal efficiently with the macroscopic world, these protein assemblies contain highly coordinated moving parts.

Since Alberts wrote those words, the recognized sophistication of the machinery of life has increased enormously. In order to give the lay reader a taste of the functional complexity of the molecular level of life, below I briefly describe one example of such machinery.

### (1) *The structure of the bacterial flagellum*

The bacterial flagellum is literally an outboard motor that some bacteria use to swim. Since its very structure so clearly embodies its purpose, the flagellum has rightly been called the "poster child" of intelligent design.[34] As illustrated by the cartoon in Figure 5.2, the structure consists of a number of discrete parts that work together to produce flagellar rotary motion. As labeled in the figure, the long, whip-like, tail filament acts as a propeller, pushing against the watery environment as it is rotated by the motor, propelling the bacterium forward. The propeller is attached to the drive shaft of the structure by means of a "hook" region, which acts as a universal joint. The purpose of a universal joint is to smoothly transmit the rotary motion from the plane of the motor to the propeller, which is oriented in a different plane. The motor itself is constructed to use a flow of acid (protons) from the exterior of the cell to the interior to power its rotation, much as the flow of water over a dam can turn a turbine. The motor is encircled by a stator against which the motor pushes, and which keeps the apparatus stationary within the plane of the bacterial cell's membrane. Other parts of the flagellum act as a bushing to allow the drive shaft to pass through the cell membrane.

The description above, of course, is quite superficial. Each of the parts mentioned itself consists of one or more complex proteins, many of whose specific structural details are necessary for its subfunction. As an example, consider just the flagellar hook. Details of the working of the hook/universal joint have recently been elucidated by the powerful new technique of cryoelectron microscopy. The structure was seen to be composed of multiple copies of the ~400-amino-acid-residue protein FlgE arranged
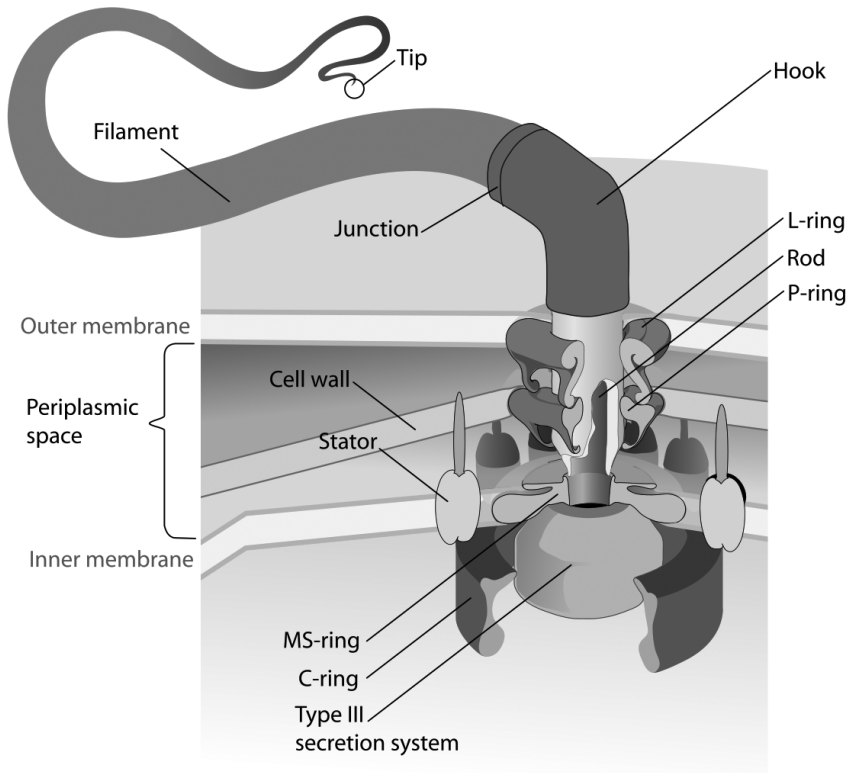
**Figure 5.2** The bacterial flagellum (Wikimedia Commons).

into eleven protofilaments that form a hollow microtubular structure. In order for the reader to glimpse its complexity, a short excerpt from the paper is provided below:[35]

Dynamic changes in intermolecular interactions. The smooth compression and extension of the protofilament [of the hook] are achieved also by dynamic changes in intersubunit interactions. The overall changes of intersubunit interactions can be depicted well by comparing two sets of models, each consisting of an array of four neighboring subunits, in which the middle two subunits are from the shortest and longest protofilaments, respectively. Domains D0 and Dc form one compact domain D0–Dc consisting of the N- and C-terminal α-helices and a long β-hairpin (residues 1–71 and 358–402), and this domain is tilted by about 17° from the tubular axis of the hook. Within each protofilament, the bottom of the N-terminal helix of the upper subunit is located on the top of the C-terminal helix with relatively large gaps of 6.3 and 12.5 Å in the short and long protofilaments, respectively. The bottom of the C-terminal helix of the upper subunit axially overlaps with the top of the C-terminal helix of the lower subunit to allow their mutual sliding for protofilament compression and extension. The relative disposition of the C-terminal helices between the neighboring protofilaments is

well maintained between subunits 0 and 5 but shows a slight axial shift between subunits 0 and 6 and a larger axial shift between subunits 0 and 11. Residues Gly 329–Asp 330 of subunit 0 at the tip of a short β-hairpin of domain D1 interact with residues Ala 39–Asp 40 of subunit 5 in the distal part of the long β-hairpin of domain Dc, and this interaction does not change by protofilament compression and extension, indicating the importance of the long β-hairpin of domain Dc for the structural stability of the hook . . . .

As the above excerpt illustrates, a profound lesson of science's deeper penetration into the molecular foundation of life is that, for molecular machinery to function, an astounding number of details must be attended to.

### *(2)  Regulation of flagellum construction*

The structure of molecular machinery such as the flagellum is the end result of a process of carefully coordinated construction. Unlike human-made machines, which can be assembled by factory workers fitting the proper pieces in the proper order, cellular machines have to be put together by a fully automated process. At the least, this requires the protein pieces of the final machinery to have geometrically and chemically complementary surfaces with which to bind specifically to the proper neighboring pieces in the final assembly and to avoid improper interactions with incorrect proteins. Lacking such binding surfaces, the pieces would float apart. Thus, even if analogous proteins that had all other properties of the flagellum components were present in a cell, but lacked the necessary complementary surfaces to bind their correct partners, no functioning machine would be produced.

For particularly complex machinery such as the flagellum much more is required.[36] The protein pieces of the machinery have to be available at the correct time and place. This requires the assistance of other proteins that do not appear in the final structure but are necessary for its construction. Briefly, the multiple genes coding for proteins of the flagellum are grouped together in a bacterial genome.[37] The first gene to be activated is a "master regulator", which codes for a protein that activates a second set of genes. This set contains the components of the flagellum that appear in its base—inside the cell and cell membrane—and that are needed to help build the more distant parts. Among the genes activated by the master regulator is one that codes for a secondary regulator that activates a second set of flagellar genes, ones that code for the middle regions. Among the genes activated by the secondary regulator is one that codes for a tertiary regulator that activates the last set of genes, ones that code for the outside region of the flagellar tail and cap. Among these genes are also ones that code for chaperone proteins—proteins which bind to and escort component parts to the flagellum construction sites but which do not appear in the final structure.

## 3.  Criticism and replies

As part of a discussion of why the irreducibly complex nature of the bacterial flagellum is a severe difficulty for Darwinian evolution and a strong pointer to purposeful design,

in 1996 in *Darwin's Black Box* I surveyed the scientific literature and showed there was up to that point no serious scientific work directed at showing how such a complex, functional structure could be produced by random mutation and natural selection. Fully a decade later several Darwinian biologists agreed with that assessment and issued a call to arms for the research to begin. Under the uncertain section-title "An experimental research programme?" the authors candidly admitted that no research had been done on flagellum evolution until that point.[38] "In recent years, flagellar biologists have made astonishing progress in understanding the structure, function and regulation of bacterial flagella . . . However, the flagellar research community has scarcely begun to consider how these systems have evolved."

Since its publication in 2006, however, the authors' challenge hasn't been taken up, either by other researchers or by the authors themselves. Twenty-five years after *Darwin's Black Box* highlighted the difficulty, the stunningly complex molecular machine is no closer to receiving a Darwinian account. This includes any possible scenario in which the type III secretory system (TTSS) might have been a stepping stone on a Darwinian pathway to the flagellum. Because it contains proteins similar to some of the proteins of the flagellum, some biologists speculated that such might be the case.[39] However, no experiments or detailed explanations showing how a Darwinian mechanism might have produced the TTSS, flagellum, or a transition between the two have been published. What's more, the current consensus is that the TTSS is likely to have been derived from the flagellum rather than the reverse.[40] Yet a scenario in which an unexplained, more-complex machine loses parts to give rise to a functioning, less-complex machine is not a Darwinian explanation for either.

### 3.a. Comparative difficulty

In discussing the evolution of such an enormously complex molecular machine as the bacterial flagellum, it can be quite difficult to do justice to the scale of the problem. The previous quotation from a paper on the details of just the hook region were one attempt to do so. Another way to begin to grasp the scale is to consider the challenge to the Darwinian mechanism of explaining even a much simpler interactive structure. Arguably the simplest biochemical structure that requires two components to interact is a disulfide (sometimes spelled "disulphide") bond. A disulfide bond is formed when the side chains of two cysteine amino acid residues react with each other. Thus, to form a disulfide bond, two cysteines are required—one by itself is insufficient. An analogy from ordinary life is a simple hook-and-eye latch, which can be used to hold a door closed. The hook or eye by itself doesn't work for that purpose; the combination is needed.

Yet even the formation of a simple disulfide bond by Darwinian processes is difficult to account for. In 2008 the journal *Biology Direct* published a theoretical, "concept" paper entitled "The Look-ahead Effect of Phenotypic Mutations," which concerned the problem. As the authors wrote,[41] "The evolution of complex molecular traits such as disulphide bridges often requires multiple mutations. The intermediate steps in such evolutionary trajectories are likely to be selectively neutral or deleterious. Therefore, large populations and long times may be required to evolve such traits."

The journal editor Eugene Koonin was excited about the prospect of addressing that fundamental problem within a Darwinian framework. Acting as one of the reviewers of the manuscript himself, he commented:[42]

> The idea of this paper is as brilliant as it is pretty obvious . . . in retrospect. A novel solution is offered to the old enigma of the evolution of complex features in proteins that require two or more mutations (emergence of a disulphide bond is a straightforward example) . . . From my perspective, this is a genuinely important work.

In the intervening years the proposal has not received much attention, and there are a number of difficulties with it.[43] However, my point here is that the enthusiasm Koonin (a prominent scientist) exhibits in his comment bespeaks the severe difficulty of accounting in Darwinian terms for even the *simplest* example of cooperativity at the molecular level of life. Yet a theory that can't easily account for a simpler example is quite unlikely to account for a much more complex one.

### 3.b.  Devolution

The difficulty of accounting for the evolution of the early stages of complex systems—including irreducible ones—is the chief conceptual problem for the Darwinian mechanism, because a blind, undirected process cannot plan ahead. The difficulty was evident even in the nineteenth century when the molecular basis of life was unknown. As science has advanced, further severe fundamental problems have been uncovered. The most serious of these is the nature of the molecular changes—mutations—underlying helpful, positively selected organismal traits.

As we now know, mutations are changes in molecules—in the protein machinery of the cell and the DNA that codes for it. Thus properly evaluating the scope of Darwin's mechanism requires the ability to identify and track underlying mutations over many generations. That was for all intents and purposes impossible to do in the necessary detail until just the past few decades. It has only been about twenty years since the technology to easily sequence DNA has become available. As the sophistication of the technology increases and its price decreases, more and more pertinent data are accumulating.

As I discussed in *Darwin Devolves* (2019), a surprising result of evolutionary DNA sequencing experiments is that the large majority of beneficial mutations that sweep through a species's population as a consequence of natural selection have been found to actually *degrade* or *destroy* preexisting genes. The phenomenon appears to be universal; it can be seen over short and long time scales, and in organisms ranging from bacteria to mammals. For example, a handful of mutations have been selected in the past ten thousand years in populations of humans who live in malarious regions of the world.[44] The mutations confer a measure of resistance to the deadly disease. Yet most of the mutations break pre-existing genes. Apparently the loss of the gene is less deleterious to the species than is susceptibility to malaria. In the largest laboratory evolution experiment ever reported with microorganisms—lasting more than 50,000

generations and involving trillions of *E. coli* cells—the thirty most beneficial, highly selected mutations all likely degraded or destroyed the genes in which they occurred.[45] Most mutations that are associated with the distinctive traits of dog breeds likewise are degradative,[46] as are most beneficial mutations distinctive for polar bears.[47] Random mutation and natural selection thus explain some adaptations, but not the building up of complex molecular systems.

Natural selection will cause a sufficiently beneficial mutation to sweep to fixation in a population, so that every member of a species then has the mutant gene. Thus beneficial degraded or nonfunctional genes will take over a population, causing a steady depletion of the species' genetic patrimony. This seems likely to be an insuperable problem for an unintelligent, undirected evolutionary mechanism such as Darwin proposed. As I argued in *Darwin Devolves*, there are compelling empirical reasons to think that Darwinian processes can produce new species and genera by degradative evolution, but cannot reach the biological classification level of family.

## 4. Conclusion

In the nineteenth century Charles Darwin proposed a novel non-design explanation for the complex features of life—natural selection sieving random variations in populations of creatures. However, accelerating progress in science has demonstrated that the foundation of life lies at the molecular level. There the tasks of life are accomplished by machinery of staggering complexity and detail, much of it irreducible. Such interactive systems are profound challenges to any undirected, unintelligent mechanism. Progress in the new millennium shows that most helpful, beneficial mutations work to degrade or destroy genes. Thus, as a candidate to explain major constructive changes in life, Darwin's mechanism has been thrown into severe doubt.

The work of a mind can be recognized in a purposeful arrangement of parts. Purposeful arrangements fill the foundation of life. The special characteristics of life compared to inanimate systems—that is, reproduction, and the potential for variation and selection—possess no ability to purposefully arrange parts. Thus the argument for intelligent design applies to both animate and inanimate systems. From these considerations we can confidently conclude that much of life was purposely designed.

## Notes

1  David Hume, *Dialogues Concerning Natural Religion,* 1779, London: Penguin Books, 1990.

2  S. C. Meyer, *Signature in the Cell: DNA and the Evidence for Intelligent Design,* New York: HarperOne, 2009, 155–159.

3  E. Sober, "The Design Argument," in *God and Design: the Teleological Argument and Modern Science*, ed. Neil A. Manson, New York: Routledge, 2003, 27–54.

4  K. R. Popper, *Realism and the Aim of Science: the Postscript to the Logic of Scientific Discovery,* Totowa, NJ: Rowman and Littlefield, 1983.

5  Thomas Aquinas, *Summa Theologiae,* New York: Benziger Bros., 1947.

6  E. Feser, *Five Proofs of the Existence of God,* San Francisco: Ignatius Press, 2017.

7  A. Avramides, "Other Minds," *The Stanford Encyclopedia of Philosophy,* ed. Edward N. Zalta, 2019, https://plato.stanford.edu/archives/sum2019/entries/other-minds/.

8  R. Kirk, "Zombies," *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta, 2019, https://plato.stanford.edu/archives/spr2019/entries/zombies/.

9  T. Reid, *Essays on the Intellectual Powers of Man*, 1785, New York: Garland Pub., 1971, Essay VI, Chapter VI.

10  "design," The Free Dictionary, https://www.thefreedictionary.com/design

11  "part," The Free Dictionary, https://www.thefreedictionary.com/part

12  M. Polanyi, "Life's Irreducible Structure," *Science* 160 (1968): 1308–1312.

13  Reid, *Essays on the Intellectual Powers of Man*.

14  Ibid.

15  Ibid.

16  M. J. Behe, *Darwin's Black Box: the Biochemical Challenge to Evolution,* New York: The Free Press, 1996; M. J. Behe, *The Edge of Evolution: the Search for the Limits of Darwinism,* New York: The Free Press, 2007; M. J. Behe, *Darwin Devolves: the New Science about DNA That Challenges Evolution,* New York: HarperOne, 2019.

17  M. J. Schiefsky, "Galen's Teleology and Functional Explanation," *Oxford Studies in Ancient Philosophy* 33 (2007): 369–400.

18  William Paley, *Natural Theology* (New York: The American Tract Society, 1802), 9–10.

19  J. C. Maxwell, "Molecules," *Nature* 8 (1873): 437–441.

20  J. Farley, *The Spontaneous Generation Controversy from Descartes to Oparin,* Baltimore: The Johns Hopkins University Press, 1979, 73.

21  J. D. Watson and F. H. Crick, "Molecular Structure of Nucleic Acid," *Nature* 171 (1953): 738.

22  J. C. Kendrew et al., "'Structure of Myoglobin: a Three-dimensional Fourier Synthesis at 2 Å. Resolution," *Nature* 185 (1960): 422–427.

23  E. Mayr, *What Evolution Is,* New York: Basic Books, 2001, 86.

24  K. Laland et al., "Does Evolutionary Theory Need a Rethink?," *Nature* 514 (2014): 161–164.

25  R. Dawkins, *River out of Eden: a Darwinian View of Life,* New York: Basic Books, 1995, 83.

26  S. Mivart, *On the Genesis of Species,* London: Macmillan, 1871.

27  Charles Darwin, *Origin of Species,* 1872, 6th edition, New York: New York University Press, 1988.

28  Darwin, *Origin of Species*, 151.

29  H. A. Orr, "Darwin v. Intelligent Design (Again)," *Boston Review,* (1996): 28–31.

30  M. J. Behe, "Reply to My Critics: a Response to Reviews of *Darwin's Black Box: the Biochemical Challenge to Evolution*," *Biology and Philosophy* 16 (2001): 685–709.

31  K. Miller, "The Mousetrap Analogy or Trapped by Design," http://www.millerandlevine.com/km/evol/DI/Mousetrap.html.

32  Orr, "Darwin v. Intelligent Design (Again)."

33  B. A. Alberts, "The Cell as a Collection of Protein Machines: Preparing the Next Generation of Molecular Biologists," *Cell* 93 (1998): 291–294.

34  K. R. Miller, "The Flagellum Unspun," in *Debating Design: from Darwin to DNA*, eds. William A. Dembski, Michael Ruse, Cambridge: Cambridge University Press, 2004, 81.

35  T. Kato et al., "Structure of the Native Supercoiled Flagellar Hook as a Universal Joint," *Nature Communications* 10 (2019): 5295–5302.

36  T. Minamino and K. Namba, "Self-assembly and Type III Protein Export of the Bacterial Flagellum," *Journal of Molecular Microbiology and Biotechnology* 7 (2001): 5–17.

37  P. Aldridge and K. T. Hughes, "Regulation of Flagellar Assembly," *Current Opinion in Microbiology* 5 (2001): 160–165.

38  M. J. Pallen and N. J. Matzke, "From *The Origin of Species* to the Origin of Bacterial Flagella," *Nature Reviews Microbiology* 4 (2006): 784–790.

39  M. H. Saier, Jr., "Evolution of Bacterial Type III Protein Secretion Systems," *Trends in Microbiology* 12 (2004): 113–115.

40  S. S. Abby and E. P. Rocha, "The Non-flagellar Type III Secretion System Evolved from the Bacterial Flagellum and Diversified into Host-cell Adapted Systems," *PLoS Genetics* 8 (2012): e1002983.

41  D. J. Whitehead et al., "The Look-ahead Effect of Phenotypic Mutations," *Biology Direct* 3 (2008): 18.

42  E. V. Koonin, "Reviewer's Comment on Whitehead et al.," *Biology Direct* 3 (2008): 18.

43  M. J. Behe, "The Old Enigma," *Uncommon Descent,* 2009, http://behe.uncommondescent.com/2009/04/%E2%80%9Cthe-old-enigma%E2%80%9D-part–3-of–3/.

44  R. Carter and K. N. Mendis, "Evolutionary and Historical Aspects of the Burden of Malaria," *Clinical Microbiology Reviews* 15 (2002): 564–594.

45  O. Tenaillon et al., "Tempo and Mode of Genome Evolution in a 50,000-generation Experiment," *Nature* 536 (2016): 165–170; R. Maddamsetti et al., "Core Genes Evolve Rapidly in the Long-term Evolution Experiment with *Escherichia coli*," *Genome Biology and Evolution* 9 (2017): 1072–1083.

46  J. J. Schoenebeck and E. A. Ostrander, "Insights into Morphology and Disease from the Dog Genome Project," *Annual Review of Cell and Developmental Biology* 30 (2014): 535–560.

47  S. Liu et al., "Population Genomics Reveal Recent Speciation and Rapid Evolutionary Adaptation in Polar Bears," *Cell* 157 (2014): 785–794.

## Bibliography

Abby, S. S., and E. P. Rocha, "The Non-flagellar Type III Secretion System Evolved from the Bacterial Flagellum and Diversified into Host-cell Adapted Systems," *PLoS Genetics* 8 (2012): e1002983.

Alberts, B. A. "'The Cell as a Collection of Protein Machines: Preparing the Next Generation of Molecular Biologists," *Cell* 93 (1998): 291–294.

Aldridge, P., and K. T. Hughes, "Regulation of Flagellar Assembly," *Current Opinion in Microbiology* 5 (2001): 160–165.

Aquinas, Thomas, *Summa Theologiae,* New York: Benziger Bros., 1947.

Avramides, A., "Other Minds," *The Stanford Encyclopedia of Philosophy,* edited by Edward N. Zalta, 2019, https://plato.stanford.edu/archives/sum2019/entries/other-minds/.

Behe, M. J., *Darwin's Black Box: The Biochemical Challenge to Evolution,* New York: The Free Press, 1996.

Behe, M. J., *Darwin Devolves: The New Science about DNA That Challenges Evolution,* New York: HarperOne, 2019.

Behe, M. J., "Reply to My Critics: a Response to Reviews of *Darwin's Black Box: the Biochemical Challenge to Evolution,*" *Biology and Philosophy* 16 (2001): 685–709.

Behe, M. J., *The Edge of Evolution: the Search for the Limits of Darwinism,* New York: The Free Press, 2007.

Behe, M. J., "The Old Enigma," *Uncommon Descent,* 2009, http://behe.uncommondescent.com/2009/04/%E2%80%9Cthe-old-enigma%E2%80%9D-part–3-of–3/

Carter, R., and K. N. Mendis, "'Evolutionary and Historical Aspects of the Burden of Malaria," *Clinical Microbiology Reviews* 15 (2002): 564–594.

Darwin, C., 1872, *Origin of Species,* 6th edition. New York: New York University Press, 1988.

Dawkins, R., *River out of Eden: a Darwinian View of Life,* New York: Basic Books, 1995.

Farley, J., *The Spontaneous Generation Controversy from Descartes to Oparin,* Baltimore: The Johns Hopkins University Press, 1979.

Feser, E., *Five Proofs of the Existence of God,* San Francisco: Ignatius Press, 2017.

Hume, David, *Dialogues Concerning Natural Religion.* London: Penguin Books, 1779.

Kato, T., et al., "Structure of the Native Supercoiled Flagellar Hook as a Universal Joint," *Nature Communications* 10 (2019): 5295–5302.

Kendrew, J. C., et al., "Structure of Myoglobin: A Three-dimensional Fourier Synthesis at 2 Å. Resolution," *Nature* 185 (1960): 422–427.

Kirk, R., "Zombies," *The Stanford Encyclopedia of Philosophy,* edited by Edward N. Zalta, 2019, https://plato.stanford.edu/archives/spr2019/entries/zombies/.

Koonin, E. V., "Reviewer's Comment on Whitehead et al.," *Biology Direct* 3 (2008): 18.

Laland, K., et al., "Does Evolutionary Theory Need a Rethink?" *Nature* 514 (2014): 161–164.

Liu, S., et al., "Population Genomics Reveal Recent Speciation and Rapid Evolutionary Adaptation in Polar Bears," *Cell* 157 (2014): 785–794.

Maddamsetti, R., et al., "Core Genes Evolve Rapidly in the Long-term Evolution Experiment with *Escherichia coli*," *Genome Biology and Evolution* 9 (2017): 1072–1083.

Mayr, E., *What Evolution Is,* New York: BasicBooks, 2001.

Maxwell, J. C., "Molecules," *Nature* 8 (1873): 437–441.

Meyer, S. C., *Signature in the Cell: DNA and the Evidence for Intelligent Design,* New York: HarperOne, 2009.

Miller, K. R., "The Flagellum Unspun," in *Debating Design: from Darwin to DNA*, edited by William A. Dembski, Michael Ruse, Cambridge: Cambridge University Press, 2004.

Miller, K., "The Mousetrap Analogy or Trapped by Design," http://www.millerandlevine.com/km/evol/DI/Mousetrap.html.

Minamino, T., and K. Namba, "Self-assembly and Type III Protein Export of the Bacterial Flagellum," *Journal of Molecular Microbiology and Biotechnology* 7 (2001): 5–17.

Mivart, S., *On the Genesis of Species,* London: Macmillan, 1871.

Orr, H. A., "Darwin v. Intelligent Design (Again)," *Boston Review* (1996): 28–31.

Paley, William, *Natural Theology,* New York: The American Tract Society, 1802.

Pallen, M. J., and N. J. Matzke, "From *The Origin of Species* to the Origin of Bacterial Flagella," *Nature Reviews Microbiology* 4 (2006): 784–790.

Polanyi, M., "Life's Irreducible Structure," *Science* 160 (1968): 1308–1312.

Popper, K. R., *Realism and the Aim of Science: The Postscript to the Logic of Scientific Discovery*, Totowa, NJ: Rowman and Littlefield, 1983.

Reid, T.m 1785. *Essays on the Intellectual Powers of Man,* New York: Garland Pub., 1971.

Saier, M. H., Jr., "Evolution of Bacterial Type III Protein Secretion Systems," *Trends in Microbiology* 12 (2004): 113–115.

Schiefsky, M. J. "Galen's Teleology and Functional Explanation," *Oxford Studies in Ancient Philosophy* 33 (2007): 369–400.

Schoenebeck, J. J., and E. A. Ostrander, "Insights into Morphology and Disease from the Dog Genome Project," *Annual Review of Cell and Developmental Biology* 30 (2014): 535–560.

Sober, E., "The Design Argument," in *God and Design: the Teleological Argument and Modern Science*, edited by Neil A. Manson, 27–54, New York: Routledge, 2003.

Tenaillon, O., et al., "Tempo and Mode of Genome Evolution in a 50,000-generation Experiment," *Nature* 536 (2016): 165–170.

Watson, J. D., and F. H. Crick, "Molecular Structure of Nucleic Acid." *Nature* 171 (1953): 738.

Whitehead, D. J., et al., "The Look-ahead Effect of Phenotypic Mutations," *Biology Direct* 3 (2008): 18.

"design," The Free Dictionary, https://www.thefreedictionary.com/design

"part," The Free Dictionary, https://www.thefreedictionary.com/part