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Reply to My Critics: A Response to Reviews of *Darwin's Black Box: The Biochemical Challenge to Evolution*

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Abstract. In *Darwin's Black Box: The Biochemical Challenge to Evolution* I argued that purposeful intelligent design, rather than Darwinian natural selection, better explains some aspects of the complexity that modern science has discovered at the molecular foundation of life. In the five years since its publication the book has been widely discussed and has received considerable criticism. Here I respond to what I deem to be the most fundamental objections. In the first part of the article I address empirical criticisms based on experimental studies alleging either that biochemical systems I discussed are not irreducibly complex or that similar systems have been demonstrated to be able to evolve by Darwinian processes. In the remainder of the article I address methodological concerns, including whether a claim of intelligent design is falsifiable and whether intelligent design is a permissible scientific conclusion.

Key words: Darwinism, evolution, falsifiability, intelligent design, irreducible complexity, natural selection

1. Empirical objections

1.1. Is the question open?

In *Darwin's Black Box* (Behe 1996) I argued there are good reasons, based on the physical structures and functional properties of some biochemical systems, to think that they had been deliberately designed. (The focus of the book was exclusively on the mechanism of evolution. I agreed that descent-with-modification is well-supported.) The necessary starting point of the book was to show that the question is open – that, contrary to common assumption, the origins of many intricate cellular systems have not yet been

adequately explained in Darwinian terms. This point has met with general agreement. While most reviewers disagreed (often emphatically) with my proposal of intelligent design, most did admit to a current lack of Darwinian explanations. Here is a sampling of comments on the particular question of whether successful Darwinian accounts have yet been offered for complex biochemical systems:

> Microbiologist James Shapiro of the University of Chicago wrote in *National Review* that "There are no detailed Darwinian accounts for the evolution of any fundamental biochemical or cellular system, only a variety of wishful speculations" (Shapiro 1996). In *Nature* University of Chicago evolutionary biologist Jerry Coyne stated, "There is no doubt that the pathways described by Behe are dauntingly complex, and their evolution will be hard to unravel. . . . [W]e may forever be unable to envisage the first proto-pathways" (Coyne 1996). In *Trends in Ecology and Evolution* Tom Cavalier-Smith, an evolutionary biologist at the University of British Columbia, commented, "For none of the cases mentioned by Behe is there yet a comprehensive and detailed explanation of the probable steps in the evolution of the observed complexity. The problems have indeed been sorely neglected – though Behe repeatedly exaggerates this neglect with such hyperboles as 'an eerie and complete silence"' (Cavalier-Smith 1997). University College, London, evolutionary biologist Andrew Pomiankowski agreed in *New Scientist*, "Pick up any biochemistry textbook, and you will find perhaps two or three references to evolution. Turn to one of these and you will be lucky to find anything better than 'evolution selects the fittest molecules for their biological function"' (Pomiankowski 1996). In *American Scientist* Yale molecular biologist Robert Dorit averred, "In a narrow sense, Behe is correct when he argues that we do not yet fully understand the evolution of the flagellar motor or the blood clotting cascade" (Dorit 1997).

Several scientists, on the other hand, have maintained that experimental evidence is actually already in hand showing either that the systems I described are not irreducibly complex ("irreducibly complex" means roughly that if one removes a component from a system, function is lost; much more about this later) or that similar systems can be produced by natural selection. In the next two sections I will address several such assertions. As I will briefly demonstrate, the arguments rest on mistaken readings or faulty interpretations of the data.

1.2. Is an "irreducibly complex" biochemical system actually reducible?

In its Feb/March 1997 issue, the Massachusetts Institute of Technology publication *Boston Review* featured a symposium discussing *Darwin's Black Box* and Richard Dawkins' *Climbing Mount Improbable*. Among the dozen essays was one by Russell Doolittle, an eminent biochemist at the University of California, San Diego, and member of the National Academy of Sciences. Doolittle took direct issue with my claims regarding the blood clotting system. I had devoted a chapter of *Darwin's Black Box* to blood clotting, asserting that it is an irreducibly complex system, does not fit well within a Darwinian framework, and that "*no one on earth has the vaguest idea how the coagulation cascade came to be*" (Behe 1996: 97; emphasis in the original). Doolittle, an expert on blood clotting, disagreed.

Professor Doolittle cited a paper by Bugge et al. (1996a), entitled "Loss of Fibrinogen Rescues Mice from the Pleiotropic Effects of Plasminogen Deficiency." Of the paper he wrote:

> Recently the gene for plaminogen [*sic*] was knocked out of mice, and, predictably, those mice had thrombotic complications because fibrin clots could not be cleared away. Not long after that, the same workers knocked out the gene for fibrinogen in another line of mice. Again, predictably, these mice were ailing, although in this case hemorrhage was the problem. And what do you think happened when these two lines of mice were crossed? For all practical purposes, the mice lacking both genes were normal! Contrary to claims about irreducible complexity, the entire ensemble of proteins is not needed. Music and harmony can arise from a smaller orchestra (Doolittle 1997).

A closer look at Bugge et al (1996a) shows Doolittle to have misread the paper.[1] Briefly, plasminogen is the precursor of plasmin, a protein that degrades blood clots (Clots eventually have to be cleared away). Fibrinogen, on the other hand, is the precursor of fibrin, the clot material which entraps blood cells and blocks bleeding. The point of Bugge et al. (1996a) was that if one crosses the two knock-out strains, producing plasminogen-plus-fibrinogen deficiency in individual mice, the mice do not suffer the same problems that afflict mice lacking plasminogen alone[2] (Bugge et al. 1995). Since the title emphasized that mice are "rescued" from some ill-effects, one might be misled into thinking that the double-knockout mice were normal. They are not. Bugge et al. (1996a) state in their abstract, "Mice deficient in plasminogen and fibrinogen are phenotypically indistinguishable from fibrinogen-deficient mice." In other words, the double-knockouts have all the problems that mice lacking only fibrinogen were previously shown to have: they do not form clots, they hemorrhage, and the females die if they become

Table 1. Symptoms of gene knock-out mice

Lacking plasminogen[1]	*Lacking fibrinogen*[2]	*Lacking both*[3]
thrombosis	failure to clot	failure to clot
ulcers	hemorrhage	hemorrhage
high mortality	death during pregnancy	death during pregnancy

[1]Bugge et al. 1995;
[2]Suh et al. 1995;
[3]Bugge et al. 1996a.

pregnant (Suh et al. 1995) [Table 1]. They are definitely not "normal." More to the point, they have no functioning clotting system and clearly are not viable candidates for evolutionary intermediates.

Although the knock-out mice in this study are not successful models for Darwinian evolutionary development of the blood clotting system, I believe the study is nonetheless quite relevant to the question of the possible step-by-step Darwinian origin of the clotting system, for two reasons. First, because it highlights the importance of the *regulation* of biochemical systems. As Halkier (1992: 104) observed concerning the coagulation cascade: "A system of this kind cannot just be allowed to free-wheel. ... Too little or too much activity would be equally damaging for the organism. Regulation is a central issue in blood coagulation." In discussing the blood clotting system in *Darwin's Black Box*, even though I briefly noted its function of removing clots, and though I highlighted the importance of regulation elsewhere in the book, I did not count plasminogen as part of the irreducibly complex clotting cascade, because it is not involved in the actual formation of the clot (Behe 1996: 86). Nonetheless, the careful experimental work of Bugge et al (1996a) reinforces Halkier's point of the serious consequences of failure to regulate a system such as the clotting cascade. Thus the study shows that from its inception the clotting system would have to be tightly regulated. Any Darwinian scheme purporting to account for clotting, therefore, would have to demonstrate how an incipient cascade would be regulated. To the extent this creates yet another impediment to a Darwinian explanation, it leaves the field open to other possible explanations.

The second reason Bugge et al.'s results are relevant is that they confirm my claim that the system is irreducibly complex. As expected, when fibrinogen is deleted, the blood clotting cascade no longer functions. Further work by the same authors in which other components of the clotting cascade – prothrombin (Sun et al. 1998) and tissue factor (Bugge et al. 1996b) – were knocked out shows that those components are also necessary for a functioning cascade.

1.3. Has the development of irreducible complexity by Darwinian means already been experimentally demonstrated?

In his book *Finding Darwin's God* Brown University cell biologist Kenneth Miller claims that "a true acid test" of the ability of Darwinism to deal with irreducible complexity would be to "[use] the tools of molecular genetics to wipe out an existing multipart system and then see if evolution can come to the rescue with a system to replace it" (Miller 1999: 145). I agree – a decisive blow against the argument of *Darwin's Black Box* would be to experimentally demonstrate the production of an irreducibly complex biochemical system under selective pressure in a model organism. Miller then claims it has already been done. With that I completely disagree. I will show that the experimental results Miller cites do not at all justify his claims.

In a section entitled "Parts is Parts," in which he discusses the careful work over the past quarter-century of Barry Hall of the University of Rochester on the experimental evolution of a lactose-utilizing system in *E. coli*, Miller excitedly remarks:

> Think for a moment – if we were to happen upon the interlocking biochemical complexity of the reevolved lactose system, wouldn't we be impressed by the intelligence of its design? Lactose triggers a regulatory sequence that switches on the synthesis of an enzyme that then metabolizes lactose itself. The products of that successful lactose metabolism then activate the gene for the lac permease, which ensures a steady supply of lactose entering the cell. Irreducible complexity. What good would the permease be without the galactosidase? ... No good, of course. By the very same logic applied by Michael Behe to other systems, therefore, we could conclude that the system had been designed. Except we *know* that it was *not* designed. We know it evolved because we watched it happen right in the laboratory (Miller 1999: 146; Miller's emphasis)!

When one examines Hall's publications directly, however, without the intervening lens of Miller's enthusiasm, one sees that the work is entirely consistent with my claim that irreducibly complex biochemical systems require intelligent design. Indeed, I could have used it as an example in *Darwin's Black Box*. I stress three points which I will discuss only briefly here. A more complete treatment can be found elsewhere (Behe et al. 2000).

1) *Only one part of the pre-existing, multi-part, lactose-utilizing system Hall studied was knocked out*. Hall eliminated the gene for just the galactosidase and clearly emphasized that:

> All of the other functions for lactose metabolism, including lactose permease and the pathways for metabolism of glucose and galactose, the products of lactose hydrolysis, remain intact, thus re-acquisition of lactose utilization requires only the evolution of a new ß-galactosidase function (Hall 1999).

Thus, contrary to Miller's own criterion for "a true acid test," a multipart system was not "wiped out" – only one component was deleted. Replacing one component of a pre-existing system does not show that a system lacking multiple components could be repaired by Darwinian means.

2) *The changes required to recover activity are quite small and can be classified as microevolution*. The function of the deleted enzyme was eventually taken over by a previously unnoticed cellular enzyme – a homologous galactosidase with an active site that was already nearly identical to that of the deleted enzyme (Hall 1999). The unmutated replacement enzyme already possessed a slight ability to hydrolyze lactose; selection of mutants simply improved the pre-existing hydrolytic activity. Importantly, by phylogenetic analysis Hall concluded that the mutations in the homologous protein he studied are the *only* ones in *E. coli* that confer the ability to hydrolyze lactose.

> The phylogenetic evidence indicates that either Asp-92 and Cys/Trp-977 are the only acceptable amino acids at those positions, or that all of the single base substitutions that might be on the pathway to other amino acid replacements at those sites are so deleterious that they constitute a deep selective valley that has not been traversed in the 2 billion years since those proteins diverged from a common ancestor (Hall 1999).

Such results hardly support extravagant claims for the creativeness of Darwinian processes. They are microevolutionary changes on the order of the development of antibiotic resistance in bacteria, and far from the development of a new irreducibly complex system that Miller claimed.

3) *The re-development of the system required intelligent intervention*. Although only one component of the multi-part system was knocked out, and only small changes were needed to restore it, yet the system still had to be artificially supported by intelligent intervention through phases when the bacteria would otherwise have been unable to utilize lactose. The intervention was in the form of the addition of isopropylthiogalactoside (IPTG), a chemical which induces the gene coding for a pre-existing permease that allows lactose to enter the cell. As Barry Hall forthrightly notes:

> At this point it is important to discuss the use of IPTG in these studies. Unless otherwise indicated, IPTG is *always* included in media

> containing lactose or other ß-galactoside sugars. The sole function of the IPTG is to induce synthesis of the lactose permease, and thus to deliver lactose to the inside of the cell. Neither the constitutive nor the inducible evolved strains grew on lactose in the absence of IPTG (Hall 1982; Hall's emphasis).

This aspect of Hall's results can be likened to an origin-of-life researcher who, at a critical point in an experiment, buys a necessary chemical from a laboratory supply house and adds it to her reaction. Whatever the results of the experiment, interesting though they may be, they crucially reflect the intelligence of the experimenter rather than the course of unaided natural processes.

Miller's writing notwithstanding, it certainly seems to me that Barry Hall's experiments actually count in favor of intelligent design, and against Darwinian evolution, because: 1) despite extensive work over the course of decades Darwinian processes were seen to produce only minor changes; and 2) intelligent intervention was necessary to keep the bacterial cells growing when the galactosidase was deleted. Such results are exactly what an intelligent design proponent would expect, given the complexity of the system.

In closing this section I would like to point out that two noted scientists, Doolittle and Miller, who were intent on showcasing the power of Darwinian processes specifically to rebut my argument for design, both cited work which on closer inspection is at best unsupportive of their position, and at worst antagonistic to it. I think this strongly confirms the view of the majority of scientific reviewers of my book who agreed that the origins of many intricate cellular systems have not yet been explained in Darwinian terms. Thus I conclude that, at the least, the question of whether Darwinian processes can account for irreducibly complex systems remains open.

1.4. Defects in the definition of irreducible complexity

The concept of irreducible complexity is central to my argument against the sufficiency of Darwinian processes. Thus it requires careful scrutiny. In *Darwin's Black Box* I defined the term in the following way:

> By irreducibly complex I mean 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 (Behe 1996: 39).

As an illustration of the concept I showed a mousetrap built of a number of pieces (spring, hammer, platform, and so on), all of which were necessary to its function. It is now clear that, although the mousetrap paradigm remains

a good one, there is some ambiguity in the written definition, as discussed below. Nonetheless, I think the definition can be repaired.

In his review of *Darwin's Black Box* in *Boston Review* University of Rochester evolutionary biologist H. Allen Orr agrees that many biological systems are "irreducibly complex," but argues that Darwinian evolution can, at least in theory, directly account for them. As I will show, in critical respects he has not followed my definition of irreducible complexity, which causes confusion. Because others have followed Orr's reasoning, I will go into detail about where it goes wrong. Nonetheless, Orr has also helpfully put his finger on an ambiguity in the definition, which I will discuss subsequently. Elimination of the ambiguity will aid in focusing attention on the difficulty for Darwinian gradualism.

Attributing the following scenario to the early 20th-century geneticist H. J. Muller, Orr writes:

> An irreducibly complex system can be built gradually by adding parts that, while initially just advantageous, become – because of later changes – essential. The logic is very simple. Some part (A) initially does some job (and not very well, perhaps). Another part (B) later gets added because it helps A. This new part isn't essential, it merely improves things. But later on, A (or something else) may change in such a way that B now becomes indispensable. This process continues as further parts get folded into the system. And at the end of the day, many parts may all be required (Orr 1996–7).

Orr later gives a biological example of what he has in mind.

> The transformation of air bladders into lungs that allowed animals to breathe atmospheric oxygen was initially just advantageous: such beasts could explore open niches – like dry land – that were unavailable to their lung-less peers. But as evolution built on this adaptation (modifying limbs for walking, for instance), we grew thoroughly terrestrial and lungs, consequently, are no longer luxuries – they are essential. The punch-line is, I think, obvious: although this process is thoroughly Darwinian, we are often left with a system that is irreducibly complex (Orr 1996–7).

In his example Orr has not adhered to the concept of irreducible complexity as I defined it. First, my definition requires that one consider "a single system." Whole organs, such as lungs or swim bladders, are not "single systems." Indeed, lung tissue contains many of the separate, irreducibly complex systems I described in *Darwin's Black Box*: cilia; intracellular transport systems; blood clotting proteins; and so on. If the origins of those molecular systems are currently unexplained, then systems built on them (such as cells

or organs) are unexplained as well. In my book I strongly emphasized that one has to examine biological systems at the molecular level to determine if they were likely produced by Darwinian processes or not. The reason is that whole cells and organs contain so many active, unknown components – a typical cell contains thousands of specific, separate macromolecules, most acting, both separately and together, in unknown ways – that one is dealing with a "black box" whose capacities are substantially obscure.[3]

A second confusion in Orr's example is with regard to the specification of the system and function under consideration. I consider the function to be the activity that the *system itself* performs: triggered snapping for a mousetrap; rotary propulsion for a flagellum; controlled formation of a barrier for the blood clotting system; and so on. My definition is intended to mean that removal of a part causes the system itself – the discrete system currently under consideration – to cease functioning. Yet it is not at all clear from Orr's example what is the system he is considering, whether lungs, swim bladders, or even the whole animal. If he is considering that the system is, say, the lungs, then what are the parts of the lungs without which they will not work? Orr does not list them, so perhaps that is not what he had in mind. The only other part, besides swim bladders and lungs, that he mentions is "limbs for walking." But vertebrate limbs are certainly not part of an irreducibly complex system that includes the lungs, at least not in my sense of the term. For example, if one removes the spring from a mousetrap, or the drive shaft from a bacterial flagellum, the systems themselves immediately cease working. But if a limb is amputated from a terrestrial vertebrate, the lungs can easily continue to function.

It seems likely that Orr had in mind that the "system" was the entire animal, and that he was thinking of an alternate conception of irreducible complexity that can perhaps be paraphrased as, "if you remove this part, the organism will eventually die," or "it will not compete successfully with other organisms." And the "function" he seems to have in mind is to help the whole animal or species prosper. So without lungs a terrestrial vertebrate would die after a minute or so, and without limbs the animal couldn't work well on land. However, that is not the same concept as I discussed. In my thinking, if one removes a part of a clearly defined, irreducibly complex system, the system itself immediately and necessarily ceases to function.

Although I think Orr's lung example is off the mark, and although the scenario doesn't help the problem of how Darwinian processes could have put together molecular systems such as I discussed, Orr's "part A, part B" scenario does identify an ambiguity in my definition of irreducible complexity. As I constructed it the definition is equivocal; it doesn't distinguish between systems that necessarily must have several parts because of the

mechanism by which they perform the task at hand, and systems which use a number of parts to do a task which could in theory be done with one. I had intended the definition to cover only the former group.

Some systems necessarily require several parts to function as they do. A simple mechanical example is a lever and fulcrum. A molecular example is the bacterial flagellum, of which I wrote: "The bacterial flagellum uses a paddling mechanism. Therefore it must meet the same requirements as other such swimming systems. Because the bacterial flagellum is necessarily composed of at least three parts – a paddle, a rotor, and a motor – it is irreducibly complex" (Behe 1996: 72). And of the intracellular transport system I wrote "Because gated transport requires a minimum of three separate components to function, it is irreducibly complex." The components were: 1) an identification mark; 2) a component to recognize the mark; and 3) a gate that is activated when the mark is recognized. Thus systems such as the flagellum and intracellular transport must have several components to do their jobs the way they do them. They do not fit Orr's scenario – there is no single part A that does the job, even poorly, so that a part B can come along later to help it.

However, one can indeed imagine a different type of molecular system where a task can be performed by one part. Perhaps some protein has a weak activity by itself, and another protein comes along to act as Orr's part B, perhaps by binding to the first protein and stabilizing the active conformation.[4] If that were to happen further mutations might change the system such that, although it functioned when both components were present, in the absence of part B, part A wouldn't have even a weak activity. Nonetheless, as can be seen from the fact that the system started out with just one component (Orr's part A), there is nothing about the mechanism of the task that makes it impossible for it to be carried out by a single component. Thus we have two conceptually distinguishable categories: 1) one in which a given task can theoretically be done by a given mechanism using a single component, but in fact several components are used by the cell; and 2) one in which more than one component is necessarily required to carry out a given task by a given mechanism.

Although I only intended to include the second category, my definition of irreducible complexity currently does not distinguish between the two. Fortunately, however, the confusion does not affect the science and the defect can be repaired easily enough by inserting a word to define irreducible complexity as: a single system which is *necessarily* 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. I think that, with the discussion above in mind, such a definition would

include those systems I discussed (the flagellum, mousetrap, and others) while excluding even molecular instances of the "part A, part B" situation Orr had in mind.

After defining the term in *Darwin's Black Box*, I went on to argue that irreducibly complex systems are obstacles for Darwinian explanations.

> An irreducibly complex system cannot be produced directly (that is, by continuously improving the initial function, which continues to work by the same mechanism) by slight, successive modifications of a precursor system, because any precursor to an irreducibly complex system that is missing a part is by definition nonfunctional (Behe 1996: 39).

However, commentary by Robert Pennock and others has made me realize that there is a weakness in that view of irreducible complexity. The current definition puts the focus on removing a part from an already-functioning system. Thus, seeking a counterexample to irreducible complexity, in *Tower of Babel* Pennock writes about a part in a sophisticated chronometer, whose origin is simply assumed, which breaks to give a system that he posits can nonetheless work in a simpler watch in a less demanding environment.[5] The difficult task facing Darwinian evolution, however, would not be to *remove* parts from sophisticated pre-existing systems; it would be to *bring together* components to make a new system in the first place. Thus there is an asymmetry between my current definition of irreducible complexity and the task facing natural selection. I hope to repair this defect in future work.

2. Methodological objections

2.1. Is intelligent design falsifiable?

In addition to empirical questions about the results of particular experiments and their interpretation, concerns have been expressed about whether intelligent design is a scientific theory at all. In particular, it has been claimed that intelligent design is not falsifiable or that it is tantamount to invoking a miracle, which is no explanation. Either of these features, the argument goes, disqualifies design as a scientific hypothesis. I will discuss these objections in the following two sections.[6]

Some reviewers of *Darwin's Black Box* have objected that intelligent design is not falsifiable. I will argue that it is. However, to decide whether, or by what evidence, it is falsifiable, one first has to be sure what is meant by "intelligent design." By that phrase someone might mean that the laws of nature themselves are designed to produce life and the complex systems that undergird it. In fact, something like that position has been taken by the

physicist Paul Davies and the geneticist Michael Denton in their recent books, respectively, *The Fifth Miracle: The Search for the Origin and Meaning of Life* (Davies 1999) and *Nature's Destiny: How the Laws of Biology Reveal Purpose in the Universe* (Denton 1998). That stance, although not exactly endorsed, seems at least to be acceptable to the National Academy of Sciences:

> Many religious persons, including many scientists, hold that God created the universe and the various processes driving physical and biological evolution and that these processes then resulted in the creation of galaxies, our solar system, and life on Earth. This belief, which sometimes is termed "theistic evolution," is not in disagreement with scientific explanations of evolution (National Academy of Sciences 1999: 7).

In such a view even if we observe new complex systems being produced by selection pressure in the wild or in the laboratory, design would not be falsified because it is considered to be built into natural laws. Without commenting on the merits of the position, let me just say that that is not the meaning I assign to the phrase. By "intelligent design" (ID) I mean to imply design beyond the simple laws of nature. That is, taking the laws of nature as given, are there other reasons for concluding that life and its component systems have been intentionally arranged, just as there are reasons beyond the laws of nature for concluding a mousetrap was designed? In my book, and in this article, whenever I refer to ID I mean this stronger sense of design-beyond-laws. Virtually all academic critics of my book have taken the phrase in the strong sense I meant it.

In the strong sense ID is no longer condoned by the National Academy, for a specific reason: "[I]ntelligent design ... [is] not science because [it is] not testable by the methods of science" (National Academy of Sciences 1999: 25). In his review of *Darwin's Black Box* for *Nature*, University of Chicago evolutionary biologist Jerry Coyne explains in some detail why he also thinks intelligent design is unfalsifiable.

> If one accepts Behe's idea that both evolution and creation can operate together, and that the Designer's goals are unfathomable, then one confronts an airtight theory that can't be proved wrong. I can imagine evidence that would falsify evolution (a hominid fossil in the Precambrian would do nicely), but none that could falsify Behe's composite theory. Even if, after immense effort, we are able to understand the evolution of a complex biochemical pathway, Behe could simply claim that evidence for design resides in the other unexplained pathways. Because we will never explain everything, there will always be evidence for design. This regressive ad hoc creationism may seem clever, but it is certainly not science (Coyne 1996).

Coyne's and the National Academy's conclusion that design is unfalsifiable, however, seems to be at odds with the arguments of other reviewers of my book. Clearly, Russell Doolittle, Kenneth Miller, and others have advanced scientific arguments aimed at falsifying ID. Now, one can't have it both ways. One can't say both that ID is unfalsifiable (or untestable) and that there is evidence against it. Either it is unfalsifiable and floats serenely beyond experimental reproach, or it can be criticized on the basis of our observations and is therefore testable. The fact that critical reviewers advance scientific arguments against ID (whether successfully or not) shows that intelligent design is indeed falsifiable.

In fact, *intelligent design is open to direct experimental rebuttal*. Here is a thought experiment that makes the point clear. In *Darwin's Black Box* I claimed that the bacterial flagellum was irreducibly complex and so required deliberate intelligent design. The flip side of this claim is that the flagellum can't be produced by natural selection acting on random mutation, or any other unintelligent process. To falsify such a claim, a scientist could go into the laboratory, place a bacterial species lacking a flagellum under some selective pressure (for mobility, say), grow it for ten thousand generations, and see if a flagellum – or *any* equally complex system – was produced. If that happened, my claims would be neatly disproven.

What about Professor Coyne's concern that, if one system were shown to be the result of natural selection, proponents of ID could just claim that some other system was designed? I think the objection has little force. If natural selection were shown to be capable of producing a system of a certain degree of complexity, then the presumption would be that it could produce any other system of an equal or lesser degree of complexity. If Coyne demonstrated that the flagellum (which requires approximately forty gene products) could be produced by selection, I would be rather foolish to then assert that the blood clotting system (which consists of about twenty proteins) required intelligent design.

Let's turn the tables and ask, how could one falsify a claim that a particular biochemical system was produced by Darwinian processes? (Coyne's remarks about a Precambrian fossil hominid are beside the point since I dispute the mechanism of natural selection, not common descent. I would no more expect to find a fossil hominid out of sequence than he would.) Kenneth Miller announced an "acid test" for the ability of natural selection to produce irreducible complexity. He then decided that the test had been passed, and unhesitatingly proclaimed intelligent design to be falsified ("Behe is wrong"; Miller 1999: 147). But if, as it certainly seems to me, *E. coli* actually fails the lactose-system "acid test," would Miller consider Darwinism to be falsified? Almost certainly not. He would surely say that the

experiment started with the wrong bacterial species, used the wrong selective pressure, and so on. Leave aside the question of whether that is a legitimate response or not. The point here is that ID could potentially be falsified by the results of a single series of rather straightforward experiments, such as Barry Hall conducted (Hall 1982, 1999). Darwinian evolution can't.

Does the falsifiability of the argument to design change if the possibility is left open that the designer is God or some other supernatural agent? No – not if one understands the phrase "intelligent design" in the sense which I used. Because I argue that unintelligent means cannot produce irreducibly complex systems such as I described, an experimental demonstration of the ability of natural selection to do just that would show my argument to be false, no matter who one thought the designer might otherwise have been. The only way around such a result would be to say that the designer was acting furtively during the experiment itself – and during any subsequent repetition of the experiment. In my opinion that is a defensible position if one thinks the experimenters were consciously or unconsciously biasing the results. However, I would not think it defensible to claim that supernatural agents were controlling the experiment. Although someone somewhere might conceivably be found who would take that position, I certainly would not. I would understand the results as a definitive refutation of my position.

I think Professor Coyne and the National Academy of Sciences have it exactly backwards. A strong point of intelligent design is its vulnerability to falsification.[7] A weak point of Darwinian theory is its resistance to falsification. What experimental evidence could possibly be found that would falsify the contention that complex molecular machines evolved by a Darwinian mechanism? I can think of none.

2.2. Is intelligent design equivalent to invoking a miracle?

Intelligent design has been criticized as tantamount to invoking a miracle (For example, see Futuyma 1997; Ruse 1997). Simply declaring "God did it", the argument goes, is not a scientific explanation. Furthermore, understanding is not advanced by postulating a designer that is surely more complex than the designed system one is trying to account for. Therefore intelligent design is no explanation of any kind.

I will reply to such criticisms in this section. Although I will not give a complete answer, I will strive to show that such objections do not currently have enough force to constitute an obstacle to a theory of intelligent design. Questions which I will address are the following: Is it possible that the designer of terrestrial life is a natural entity? Is it plausible that the designer is a natural entity? If the designer is a supernatural entity, is intelligent design an "explanation"? Would progress in science be stymied by a theory

of intelligent design? Must a designer be more complex than the systems it designs?

Is it possible that the designer is a natural entity? If the designer were a natural entity then questions about God, the supernatural, and miracles would be moot. Thus we can begin by asking whether it is even possible for the designer to be a natural entity. This can be divided into two questions: 1) is it logically possible? and, 2) is it physically possible? The key consideration is that of irreducible complexity. If irreducible complexity requires intelligent design, and if any natural designer must contain irreducibly complex systems, and if the universe is not infinitely old allowing infinite regress, then eventually one runs into the problem of "who designed the designer?" Nonetheless, it is at least logically possible to have a natural designer who does not contain irreducibly complex systems, because there is nothing in the concept of intelligent designer that entails irreducible complexity. "Not irreducibly complex" and "natural intelligent designer" are not contradictory terms, so the conjunction of the terms violates no logical tenet.

Logical possibility is perhaps the least demanding criterion. A more interesting question is whether a non-irreducibly-complex natural designer is physically possible. By "physically possible" I mean only that something is not contradicted by known physical laws – not that we have any evidence of it. In other words, by the phrase physically possible I intend to leave the door open to all speculative phenomena for which we do not have strong positive evidence that they are directly contrary to well-established physical principles. In this sense I think a natural intelligent designer is physically possible. As I wrote in *Darwin's Black Box*, perhaps the designer could be made of gas particles or self-organizing electromagnetic fields or something else which would strike us as fantastic, but is physically possible and does not involve irreducible complexity. It is noteworthy that serious scientists have proposed that life could exist in such places as the atmosphere of Jupiter (Shapiro1999) and that it could at least begin as clay crystals (Cairns-Smith 1985).

We may not need to resort to utterly alien life forms, however. A non-irreducibly complex entity could conceivably be based on carbon chemistry not very much unlike our own. After all, although some terrestrial biochemical systems are irreducibly complex, others aren't (such as some metabolic pathways, cell membranes, oxygen transport, etc.). Furthermore, functions that are performed by irreducibly complex terrestrial systems may be accomplished by simpler systems elsewhere. For example, the function of a mechanical mousetrap can be performed by a glue trap, which is not irreducibly complex. In speculating on the origin of life and the first cells scientists often invoke relatively simple systems that can accomplish a known

cellular function at least to a degree. Perhaps functions that are performed by irreducibly complex biochemical systems in humans can be performed by simpler systems, or somehow gotten around, while sticking with familiar chemical principles. I must admit that I am not prepared to spell out how that might be done. My purpose here is only to argue that we can't currently rigorously rule it out.

Is it plausible that the designer is a natural entity? While such designers as discussed above may be possible in the sense that there is not positive proof they cannot exist, we can ask further whether it is plausible that they actually do or did exist. Plausibility, of course, is to a large extent in the eye of the beholder. For example, while some scientists consider it highly likely that the universe is teeming with intelligent life (Shapiro 1999), others think it very probable ours is the only planet with intelligent life (Ward and Brownlee 2000). And these convictions are held despite the absence of an accepted theory for how life may originate or of much understanding of what constitutes intelligence.

The problem is the following. Currently we have knowledge of only one type of natural intelligent designer even remotely capable of conceiving such structures as are found in the cell, and that is a human. Our intelligence depends critically on physical structures in the brain which are irreducibly complex. Extrapolating from this sample of one, it may be that all possible natural designers require irreducibly complex structures which themselves were designed. If so, then at some point a supernatural designer must get into the picture.

I myself find this line of reasoning persuasive. In my estimation, although possible in a broadly permissive sense, it is not plausible that the original intelligent agent is a natural entity. The chemistry and physics that we do know weigh heavily against it. If natural intelligence depends on physical organization, then the organization seems likely to have to be enormously complex and stable over reasonable periods of time. While simpler systems may perform the tasks that irreducibly complex systems perform in terrestrial life, they would likely perform them more slowly and less efficiently, so that the complexity required for intelligence would not ultimately be achieved. Thus in my judgment it is implausible that the designer is a natural entity.

I should add that there is nothing in the previous reasoning to rule out the hypothesis that we terrestrials were designed by a natural designer which was itself designed by a supernatural designer, or that there was a series of designers between the supernatural one and us, or some variation of this. It simply means that at the beginning of the chain, input from beyond nature was required.

If the designer is a supernatural entity, is intelligent design an "explanation"? Is it a "miracle"? Let me first acknowledge that, as there could have been a series of natural designers, there could also have been a series of supernatural ones, with one designing another which eventually designed an intelligent natural being. Or several supernatural entities could have collaborated to design natural beings, or some variation of this. I am not proposing these scenarios seriously, but just to show that a bare hypothesis of intelligent design leaves open many possibilities. For simplicity, in the following discussion I will speak of just one supernatural designer which, as Thomas Aquinas might say, we will call God. In addressing the above questions I will first assume that God exists. To justify the assumption I simply note that, in addition to the majority of humankind, a number of prominent philosophers and scientists profess to believe in God's existence. Later I will consider the situation where God's existence is in dispute.

Assuming that God does exist, then, is the hypothesis of intelligent design an "explanation"? To answer this question we must first pay some attention to the limited nature of a claim of intelligent design for any designer. An assertion that some device or system was intelligently designed is *not an explanation of the mechanism* by which it was assembled. It is simply the claim that intelligent input was involved at some point in its assembly. To illustrate, a rag doll in a store might carry a tag saying "hand-sewn", but its unscrupulous manufacturers actually used automated machinery to produce it. Looking at the doll in the store we may not know how it was manufactured, but we easily apprehend that it was purposely designed, whether directly by hand, indirectly by machine, or some other means. Or consider a science fiction example. Suppose we are shown two identical-appearing hand guns. One was manufactured in a gun factory. The other is a duplicate of the first where the original gun was put in a black box, a beam shone upon it, a few dials twirled and lights blinked, and out of the box came an exact replica. Examining the two guns we may not be able to tell which was which, or we might be able to tell only after long and strenuous investigation. Yet we have no trouble at all deciding they were both intelligently designed. Furthermore, in the case of the duplicator, we may never be able to figure out the mechanism for how the second gun was made, yet the conclusion of design remains solid.

With the above examples in mind, it seems to me that a conclusion of intelligent design in cases where the designer is likely to be God is as much an explanation as a conclusion of intelligent design for cases where the designer is a natural being. One is simply asserting that design is part of the causal history of the system and that without design the system would not exist. But one is not specifying the mechanism by which it was produced. The question

of the mechanism by which the system was designed is separate from the question of whether it was designed, and may be much more difficult to answer. If the designer was in fact God, then there is good reason to suppose that the mechanism of design will forever remain beyond us. Yet, whether progress on the mechanism of design is possible or not, the conclusion of design does not absolutely require it.

Perhaps intelligent design in biochemistry is some sort of an explanation, but is it a "scientific" explanation if the designer is likely to be God? I contend that it is. Without getting into the difficult problem of trying to define science, I will just say that I think any explanation which rests wholly on empirical evidence and basic logic deserves the appellation "scientific".[8] The conclusion of intelligent design in biochemistry rests exclusively on empirical evidence – the structures and functions of the biochemical systems – plus principles of logic (for example, see Dembski's (1998) *The Design Inference* and Ratzsch's (2001) *Nature, Design, and Science*). No particular tenet of faith is involved.[9] Therefore, I consider design to be a scientific explanation (whether ultimately correct or not).

Well, if one thinks that the most plausible designer of life is God, then is the hypothesis of intelligent design tantamount to invoking a miracle?[10] I think there are actually two questions here: 1) does the hypothesis imply a miracle probably happened? and 2) if so, does the hypothesis concern the miracle itself? Yes to the first, no to the second. Although a hypothesis of the intelligent design of aspects of life may reasonably be taken to imply the involvement of supernatural agency – a "miracle" – at some (perhaps quite remote) point, it does not concern it directly. Rather, it reaches its conclusion based on tangible, empirical features of a system and proceeds from there. That, I argue, is not unprecedented in science. To illustrate the point, consider the Big Bang hypothesis. In the middle part of the 20th century the observation of galactic red shifts led to the proposal of an expanding universe and to the hypothesis that the universe had a beginning in the distant past – the Big Bang. A number of scientists thought that the Big Bang hypothesis had theistic implications.[11] After all, what might cause the beginning of nature if not something outside of nature? The actual coming-into-being of the universe may have been a supernatural event, some thought – a miracle. Nonetheless, the Big Bang hypothesis justified itself with empirical evidence, and scientific investigations started with the fact of the Big Bang itself and proceeded to examine physical consequences which flowed from it. In other words, the question of the (possibly miraculous) mechanism producing the Big Bang was bracketed; the beginning of the universe was treated as a boundary condition.

The beginning of nature may indeed have been a miracle, but the Big Bang hypothesis is a scientific one which does not concern miraculous matters.[12] I place the intelligent design hypothesis in the same category. Although the process by which some structures of life were designed may have involved supernatural agency, we can bracket that question, treat the designed structures as akin to boundary conditions, and proceed from there.

Is science stymied if we hypothesize that aspects of life were designed? Another objection to intelligent design theory is that it is a "science stopper", that it places some questions off-limits to scientific investigation and thus discourages progress. I think much of that objection arises from a failure to recognize that all scientific theories do the same. To the extent a theory proposes to explain an aspect of nature, it simultaneously claims that other explanations are incorrect, predicts that experiments that aren't designed in conformity with the theory will fail, and in that way discourages them. To illustrate, among other things Einstein's theory of relativity holds that no object with mass can travel faster than light. Certainly any person working within the framework of the theory will be discouraged from conducting extensive experiments to show that a massive object can travel faster than light (except perhaps to confirm the expected failure to do so). Some questions are just ill-formed. From the point of view of Einstein's theory, avoidance of the question of supraluminal travel is not a limitation. Rather, the theory is simply helping an investigator avoid an ill-formed question, which is a positive feature of the theory. Similarly, for intelligent design theory a question such as "How did random mutation and natural selection construct the bacterial flagellum?" is ill-formed because the theory holds that in fact the flagellum could not arise that way, and spending a lot of resources to investigate it is likely to be a waste. Again, helping investigators avoid ill-formed questions is a positive contribution which all theories seek to make. Nonetheless, a number of other empirical questions (such as those listed by Ratzsch 2001: 143) can open up to design theorists, which would not be asked in the framework of other theories.

Those skeptical of ID, who worry that science would be stuck in a blind alley if design became the majority view in biology, should relax. As a practical matter, no theory, including intelligent design, can stop scientists from investigating alternatives. If a theory could do that, then theories would never be overturned. Within the broad community of scientists there are always some who question the dominant view. Even if intelligent design theory were some day to be the majority position in biology, there is every reason to think experiments would continue to be conducted by skeptical investigators to challenge its postulates.

Must a designer be more complex than the systems it designs? The evolutionary biologist Richard Dawkins (Dawkins 1986: 141) has argued briefly that we should not entertain the notion of a supernatural designer, because such a designer would have to be more complex than the system being explained. An appeal to the more complex to explain the less complex, the argument goes, is no explanation at all. Thus we should prefer a hypothesis of Darwinian evolution to intelligent design.

It seems to me that Professor Dawkins' argument is open to question and his conclusion is not obvious. First, is it true that an appeal to the more complex cannot explain the less complex? It cannot be true in general since we do it all the time. A smooth formation of igneous rock might be explained as a lava flow from an ancient volcano, yet it is quite arguable that the volcano is more complex than the rock formation. I might explain tracks across my lawn as the result of my daughter's erratic driving. By most measures, however, the car is probably more complex than the tracks explained by reference to it. The presence of a wood-and-mud dam at a particular river might bring the conclusion that it was likely built by a beaver. All of these effects are less complex than their causes, yet most of us would be perfectly satisfied with the explanations.

Perhaps Dawkins meant in particular that an ultimate explanation of life or nature must be simple, where the chain of causation begins. Again, that is not obvious to me – perhaps the beginning of the chain of causation is infinitely complex in some sense. For purposes of argument, however, let us assume he's right in this narrower sense. Yet is it indeed true that a designer must be more complex than the systems it designs? It is not self-evidently true even for natural designers. Consider computers. Is it possible for a human to build a computer that is more complex than a human? It may be. In fact some people in the field are quite confident that one day it will happen. Even if today's computers are not as complex as human beings, given time there is no logical reason to suppose a computer can't be built that exceeded the complexity of humans by some measure.

If a natural designer can in principle be less complex than systems she designs, then why should we think a supernatural designer must be more complex than systems it designs? I can think of no reason. Like Dawkins, I am no theologian and I am ill equipped to argue about the nature and attributes of God. Nonetheless, one attribute assigned to God by theologians such as Aquinas is simplicity. If those theologians are right, perhaps there is no basis in fact for Dawkins' objection. In any event, unless and until his argument is much more fully developed I do not think it presents a barrier to a conclusion of intelligent design in biochemistry.

What if the existence of God is in dispute or is denied? So far I have assumed the existence of God. But what if the existence of God is denied at the outset, or is in dispute? Is the plausibility of the argument to design affected? As a matter of my own experience the answer is clearly yes, the argument is less plausible to those for whom God's existence is in question, and is much less plausible for those who deny God's existence. People I speak with who already believe in God generally agree with the idea of design in biology (although there are certainly exceptions), those who are in doubt are interested in the argument but often are skeptical, and as a rule those who actively deny God's existence are either very skeptical or wholly disbelieving (Apparently, the idea of a natural intelligent designer of terrestrial life is not entertained by a large percentage of people).

Without becoming entangled in philosophical or religious arguments about the existence of God, what are we to make of these various reactions? I think that one can simply view them as arising from different estimations of the strengths of competing hypotheses. As an analogy, imagine that a shipwreck marooned you on a desert island. If you see a few rocks strewn about, you might think nothing of it. But if you see some rocks on the island in a circle, then if you also think some other person may have escaped the wreck and ended up on the island, you may surmise the rocks were arranged by that other survivor, even if you have not yet encountered her face-to-face. On the other hand, if no one else was on the sunken boat and you have no reason to think another person is on the island, then you might shrug off the circle of stones as a peculiar coincidence. However, as the example becomes more and more insistent (say, instead of a circle of stones one sees a stone chimney, or stones spelling out the message "hi" vs "hello" vs "welcome, survivor") then the hypothesis of intelligent design becomes more and more plausible. It might even reach the point where, if a natural designer were nowhere to be seen, a person would judge it more likely that God was arranging the stones than that it was a coincidence.[13]

To many theists such as myself, the state of the biological evidence is such that the hypothesis of design is more compelling than that unintelligent processes produced the irreducibly complex systems seen in the cell, like the shipwreck survivor who thought someone else might be on the island. However, like the survivor of the shipwreck who thinks no one else is on the island, many (although not all) agnostics and nontheists draw the line differently, and reach the opposite conclusion. This is unsurprising; it is frequently the case in science that when new theories are proposed people judge the evidence differently. The only unusual (but not unprecedented) feature here is that a person's judgment on the existence of God enters into the balance.

Nonetheless, the more common – and most important – feature is that people's judgments can be affected by the further development of the evidence, just as in the shipwreck example an opinion might change if the evidence became more compelling.[14] If future work shows natural selection capable of doing more than skeptics of Darwinism had thought, or if another mechanism is discovered which can generate irreducible complexity without intelligent input, then fewer people will deem intelligent design to be a sound hypothesis. On the other hand, if further investigations exacerbate problems for Darwinism and no plausible alternative explanation appears, or especially if design is seen to have real empirical payoffs, then it is likely that more people will be attracted to the idea of intelligent design as I have developed it.

Notes

[1] Doolittle's point has been echoed by other critics of intelligent design. For example, in *Free Inquiry* Michael Ruse, a prominent Darwinian scholar, wrote:

> Behe is a real scientist, but this case for the impossibility of a small-step natural origin of biological complexity has been trampled upon contemptuously by the scientists working in the field. They think his grasp of the pertinent science is weak and his knowledge of the literature curiously (although conveniently) outdated.
>
> For example, far from the evolution of clotting being a mystery, the past three decades of work by Russell Doolittle and others has thrown significant light on the ways in which clotting came into being. More than this, it can be shown that the clotting mechanism does not have to be a one-step phenomenon with everything already in place and functioning. One step in the cascade involves fibrinogen, required for clotting, and another, plaminogen [*sic*], required for clearing clots away (Ruse 1998).

And Ruse went on to quote Doolittle's passage from *Boston Review* cited above.

[2] The intent of Bugge et al. (1996a) was to determine if plasminogen had any other function in the organism besides its role in blood clotting. The fact that knocking out fibrinogen relieved all the symptoms of plasminogen deficiency led them to conclude that it did not.

[3] As an aside, ordinary mechanical contraptions such as a mousetrap or a clock don't have to be examined at the molecular level because the parts are not themselves complex assemblages of active components, as are cells. However, more sophisticated artificial devices, such as computers, may indeed have to be examined at the molecular – or at least microscopic – level to determine if they are irreducibly complex.

[4] One example of this could be myoglobin/hemoglobin. The single-chain myoglobin binds oxygen by itself, but several myoglobin-like chains in tetrameric hemoglobin bind oxygen with greater flexibility. I discussed the potential evolution of hemoglobin from a myoglobin-like precursor in a section entitled "Making Distinctions" (Behe 1996: 205–208).

[5] In *Tower of Babel: The Evidence Against the New Creationism* philosopher Robert Pennock protests that I have tried to get an empirical conclusion from a conceptual argument (Pennock 1999: 267–268) mostly, it seems, because of my unfortunate use of the phrase "by definition" in describing the problem irreducible complexity poses to Darwinism. However, Pennock seriously misunderstands my argument, which is a scientific/empirical one, not a philosophical/a

priori one. The confusion may be partly my fault because, as a scientist, I was not sensitive to how a professional philosopher might construe my words, that the phrase "by definition" would be a red flag and become the unintended focus of scrutiny to the exclusion of the real empirical difficulties of constructing irreducibly complex biochemical systems. In fact I was not attempting to rule out Darwinian explanations a priori (nor did I say that I was) or to "prove" in a logical sense that Darwinian processes could not possibly have produced irreducibly complex systems. Such a heavy burden of logical proof, completely ruling out alternative explanations, is rarely if ever borne in science, even by time-tested theories, and I do not feel the need to take it on either. For his part, Pennock focuses on the phrase "by definition" to the point of overlooking important qualifications I made and examples I gave, and he ignores or dismisses without engagement the empirical problems I concentrated on. Pennock's assertion notwithstanding, I did not claim that "there could never be any functional intermediates that natural selection could have selected for on the way to *any* irreducibly complex system" (Pennock 1999: 267–268). On the contrary, I forthrightly wrote that "Even if a system is irreducibly complex (and thus cannot have been produced directly), however, one cannot definitively rule out the possibility of an indirect, circuitous route," continuing that "As the complexity of an interacting system increases, though, the likelihood of such an indirect route drops precipitously" (Behe 1996: 40). Thus the essence of my argument is probabilistic rather than definitional.

[6] These questions have recently been addressed at length by Ratzsch (2001) who concludes that design can indeed be a legitimate scientific conclusion. For example, he writes: "However, if one takes the second option – science as an attempt to discover as much as possible concerning the structure, operation, and history of actual reality, whatever that reality may be or include – then the situation is very different. In particular, prohibition on the supernatural does not even superficially appear to emerge out of the definition or primary aim of science. In fact, under this second conception, science – aimed now at the truth, whatever the truth turns out to be – might be required to think about the possibilities of supernatural causation and phenomena within even the empirical realm" (p. 95).

[7] Indeed, some of my religious critics dislike intelligent design theory precisely because they worry that it will be falsified, and thus religion will appear to suffer another blow from science. See, for example, Flietstra 1998 and Oakes 2001.

[8] On the other hand, if an explanation depends critically on specific tenets of a particular faith, such as the Trinity or Incarnation, or on sacred texts, then that of course is not a scientific explanation.

[9] I do not regard the existence of God as a tenet of faith, since it is a subject of philosophical argument from first principles. Of course, different persons arrive at different conclusions about God's existence, but that only means the arguments persuade some people and not others. It does not mean that the affirmation of God's existence need be dogmatic.

[10] I am using the term miracle here to mean "the involvement at some point of supernatural agency". One should be careful to note, however, that the "some point" doesn't have to be during the course of the universe's history, but could be at its inception. Thus, even if one does think the designer is God, subscribing to a theory of intelligent design does not necessarily commit one to miracles in the sense of "intervention" or the contravening of the laws of nature – no more than thinking that the laws of nature were designed by God (a view, as we've seen, condoned by the National Academy of Sciences (National Academy of Sciences 1999)). In either case one could hold that the information for the subsequent unfolding of life was present at the very start of the universe. In one case, the information is present just in general laws. In the other case, in addition to general laws, much more information is present in other factors too, such as initial conditions. The difference might boil down simply to the

question of whether there was more or less explicit design information present at the beginning – hardly a point of principle.

[11] The question of the theistic implications of the Big Bang hypothesis has been treated explicitly in, for example, Craig and Smith (1993). Furthermore, that scientists recognized the Big Bang had theistic implications can sometimes be seen in statements by those who didn't welcome them. For example, in an article entitled "Down with the Big Bang," whose subtitle calls the theory "philosophically unacceptable," former *Nature* editor John Maddox wrote "Creationists and those of similar persuasions seeking support for their opinions have ample justification in the doctrine of the Big Bang. That, they might say, is when (and how) the Universe was created" (Maddox 1989).

[12] Of course, some scientists are now trying to explain the Big Bang itself (For example, see Guth 1997). Nonetheless, the point remains that for decades there was no attempt at a scientific explanation for the Big Bang. Thus for a time science quietly accepted a possibly miraculous beginning to the universe.

[13] Of course the preceding example is not directly parallel to biological examples because there are claims that the apparently-designed biological systems can be explained by natural processes, and are not sheer coincidence. However, if one examines those claims and becomes convinced they are incorrect, then biological examples take on the same force as nonbiological ones.

[14] To be sure, people might not respond linearly to the evidence.

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