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Deconstructing Design: A Strategy for Defending Science

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Despite its legal and scientific failings, the "intelligent design" (ID) movement has been a public relations success story in the United States. By first creating doubts about the adequacy of evolution to account for the complexity of life, the ID movement has invoked the values of "fairness" and "openness" to argue for inclusion in the classroom and curriculum. In this way, it has attempted to lay claim to the very principles of critical analysis and open discussion at the heart of the scientific enterprise, leaving many researchers in doubt as to how to respond to these challenges.

Specific case studies, including the blood-clotting cascade and data from the human genome, show how scientists can have a leading role in deconstructing the arguments advanced in favor of ID. The key to this strategy is remarkably simple and was at the heart of the landmark 2005 Kitzmiller v. Dover trial on ID. It is for researchers to take the claims made by ID proponents seriously, and then to follow them to their logical scientific conclusions. When this is done effectively, the hypothesis of "design" can be publicly falsified in ways that are understandable to laypeople and decision makers in education.

We live and work in the midst of a remarkable dualism. Today, 150 years after the publication of *On the Origin of Species*, the scientific foundations of evolutionary biology have never been stronger. Indeed, as Theodosius Dobzhansky (1973) famously wrote, "Nothing in biology makes sense except in the light of evolution," and the papers presented at this conference are eloquent testament to the validity of that assessment. Nonetheless, in the public mind, evolution remains a "controversial" idea, a mere "theory" rejected by as many as half of all Americans. Widespread opposition to evolution has led some states to weaken their science education standards, forced teachers to deemphasize evolutionary principles in biology, and placed pressure on authors and publishers to include "alternate" theories in their textbook offerings. Although this is primarily an American phenomenon, it is worth noting that antievolution movements have made major gains in Europe as well (Graebsch and Schiermeier 2006), suggesting that in the near future, this may become a truly international issue for scientists and educators.

Although I am a cell biologist, my own work as a textbook coauthor with my colleague Joseph S. Levine (Miller and Levine 2008) has forced us to confront these issues and to develop effective responses to a number of antievolution arguments and movements. In 2002, for example, one of our textbooks was chosen for use in the high schools of Cobb County, Georgia. Community reaction against the treatment of evolution in several textbooks, including ours, led to a petition drive to include creationism in the county's curriculum. The Cobb County School Board attempted to deal with the popular pressure by fashioning what they viewed as a compromise. The Board required that a sticker be affixed to each book warning students that "evolution is a theory, not a fact, regarding the origin of living things" (Holden 2002). Several parents, contending that these stickers represented a government attempt to advance a particular religious point of view, sued the School Board in Federal court, and a week-long trial resulted. The court ruled (Holden 2005) in favor of those plaintiffs, and the stickers have now been removed. Late in 2005, a more highly publicized trial, known legally as Kitzmiller v. Dover Area School District, took place in another Federal court, and I discuss some of the details of that trial below.

In many states, the struggle over evolution has also found its way into the political arena. In fact, evolution was *the* pressing election issue in two American states in 2006—Ohio and Kansas. Each elects their state board of education in highly politicized contests, and in 2006, the candidates' positions on evolution seemed to be the only issue that mattered to many voters. According to a newspaper report (Stephens 2006), a radio talk show host in Cleveland described one of these contests involving Deborah Owens Fink, the leader of antievolution forces on the Ohio Board, like this: "If you believe in God, creation, and true science, vote for Debbie. If you believe in evolution, abortion, and sin—vote for her opponent."

With rhetoric like that, one might have expected Ms. Fink to cruise to an easy win. In reality, proevolution candidates, including Ms. Fink's opponent, swept to victory in Ohio, and proevolution candidates also took control of the Kansas Board of Education. Evolution supporters in Kansas further strengthened their hold on the Board in the recent 2008 elections. The reasons, in each state, were effective proscience campaigns mounted by coalitions of scientists, educators, health professionals, and others interested in quality science education. Given a choice, the American people will choose science every time, but only if we in the scientific and educational communities put the issue on the table clearly and forcefully. Being an optimist by nature, I hope we can continue to do just that.

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THE DEVIL IN DOVER

Of all the recent battles over evolution, by far the most spectacular took place in the small community of Dover, Pennsylvania in 2004 and 2005. Late in 2004, Dover's Board of Education voted to instruct the teachers in the Dover Area High School to prepare a biology curriculum that included an antievolution concept known as "intelligent design" (ID). Although the Dover science faculty courageously refused to go along, the Board persisted. They purchased classroom sets of an ID textbook known as *Of Pandas and People* (Davis and Kenyon 1993) and wrote a four-paragraph statement on ID to be read to students. When it was clear that the Board would go ahead with this policy, 11 parents filed a lawsuit asking that the ID policy be rescinded. The case moved rapidly to trial, gaining media attention all the while, and convened in the Federal Courtroom of Judge John E. Jones III in Harrisburg on September 26, 2005.

What is the concept called "intelligent design" that was at the heart of this battle? The best way to begin might be by defining what ID does not mean. Most theists, those individuals who believe in a God of any sort, would argue that there is a plan and pattern to existence. As such, they might well agree, in a certain sense, that there is indeed an "intelligent" order to existence. Valid or not, this is a philosophical argument that lies outside the purview of the natural sciences. It does not so much challenge the theory of evolution as define a view of how evolutionary science may be viewed in a philosophy of nature.

That is not, however, how ID was presented to the citizens and schoolchildren of Dover. In the context of public discourse in the United States, ID is a claim that "design," meaning outside intelligent intervention, is required to account for the origins of living organisms. As such, it clearly is a doctrine of *special creation*. The reason for this assessment is that when one states that the bacterial flagellum, or the blood-clotting cascade, or even the animals of the Cambrian period were "designed," what one really means is that they were *created*. One cannot speak of the "design" of a biochemical system without also claiming that the genes to specify that system were, in the most direct sense, created by an intelligence outside of nature. Pointing out that ID is a form of creationism does not, of course, mean that it is wrong; rather, it is only to call it by a proper and accurate name.

For advocates of ID, the looming court case was their chance to crush those whom they scorned as "Darwinists" in front of a conservative Republican judge. John E. Jones III, who would preside over the case, had been named to the bench in 2002 by President George W. Bush. William Dembski, a leading advocate of ID who at first agreed to appear as an expert witness in the trial, even proposed a "strategy for interrogating the Darwinists to, as it were, squeeze the truth out of them." Dr. Dembski did not appear in court, citing disagreements with attorneys representing the Dover Board, and the case certainly did not go as he expected. The actual result of the 7-week trial was a crushing defeat for ID, as described by the Judge himself in a recent interview (Gitschier 2008). So completely did the case for ID as science collapse that the citizens of Dover did not feel the need to wait for the judge's decision. Only a few days after arguments in the trial concluded, voters turned out the pro-ID school board, replacing them with a reform slate that had strongly opposed the ID policy. Six weeks later, the judge filed his own opinion. As reported in *The New York Times*, "In the nation's first case to test the legal merits of intelligent design, the judge, John E. Jones III, issued a broad, stinging rebuke to its advocates and provided strong support for scientists who have fought to bar intelligent design from the science curriculum" (Goodstein 2005).

There were many elements to the success of the plaintiffs in the Dover trial, some of which have been discussed by other speakers at this meeting (Kevin Padian, Barbara Forrest, and I served as expert witnesses in the trial, and Eugenie Scott, Director of the National Center for Science Education, had a key role in coordinating the case). In particular, the religious origins of the ID movement were laid bare, clearly demonstrating that the intentions of the Dover Board were in clear violation of the First Amendment of the U.S. Constitution. For legal reasons, this may have been the single most important element of the trial. Many Americans, however, might not be bothered by such connections. After all, if one has genuine scientific evidence of the work of a "designer," it only follows that people of faith would seek to use the public schools to spread the word. And, they might ask, if the science were legitimate, what would be the harm of that?

For that reason, the Dover Board argued that ID was in fact sound science and that its presence in the classroom would serve a legitimate secular purpose. Aside from pointing out that ID is not generally accepted by the scientific community—an important point to be sure—how might one counter that assertion? As I suggest below, the answer is remarkably simple. We should take the suggestion of "design" in biological systems as seriously as we do any scientific proposal, follow it up, and see where it leads.

AN ENDURING APPEAL

It is abundantly clear to the members of the scientific community that the advocates of ID have not made a convincing scientific case. Indeed, just a few months after the conclusion of the trial, even law professor Phillip Johnson, one of the founders of the ID movement, admitted frankly that the scientific people in ID had let him down:

> I also don't think that there is really a theory of intelligent design at the present time to propose as a comparable alternative to the Darwinian theory, which is, whatever errors it might contain, a fully worked out scheme. There is no intelligent design theory that's comparable. Working out a positive theory is the job of the scientific people that we have affiliated with the movement. Some of them are quite convinced that it's doable, but that's for them to prove… No product is ready for competition in the educational world.
>
> *As quoted in D'Agostino 2006.*

Nonetheless, despite these scientific failings, ID has been a public relations success story. A recent study (Miller et al. 2006) placed the United States second to last in the

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extent to which the citizens of 34 different nations accepted the theory of evolution. Among the countries studied, only Turkey ranked lower in terms of support for evolution. The reasons for this should be obvious. Not only do individuals in the United States show a much higher degree of religious belief than those of most other industrialized countries, but these individuals also seem to be at the very center of the antievolution movement. Organizations such as *Answers in Genesis* and *The Discovery Institute* turn out steady streams of antievolution material, much of it freely available on the web. Adding to this, one might include the recently opened Creation Museum in northern Kentucky, and *Expelled*, a popular 2008 documentary purporting to show links between evolutionary theory and the Nazi Holocaust. Given such steady and skillful promotion, it seems clear that the appeal of ID creationism will endure.

What is the source of this appeal? I contend that ID succeeds in the public imagination because it seems to fill a vacuum in our understanding of biology. Any biological structure or process that is not yet fully understood contributes to this vacuum, and ID fills it at a stroke. Indeed, the critics of evolution find it easy to point to complex molecular machines such as the ribosome and then challenge the scientific community to provide detailed, step-by-step evolutionary explanations for their origins. When such explanations are not forthcoming, they announce that "design" must be the answer. Using a strategy such as this, the vast reservoir of unsolved and unexplored scientific problems becomes grist for the creationist mill. In the minds of many members of the general public, it actually becomes "evidence" for the hypothesis of ID.

The appeal of the "design" argument, therefore, is the closure that it seems to provide to such questions. Where evolution seems to offer open-ended inquiry and unresolved questions, ID brings things to a neat and tidy conclusion. Its appeal is that it seems to provide answers where science supplies only questions and certainty where science calls for doubt.

DECONSTRUCTING "DESIGN"

One of the keys to the public success of the ID movement has been the tacit agreement the scientific community has given to the creationist argument that "design requires a designer." Because, to most laypeople, the form and function of everything from the human body to a muscle cell amount to "design," the scientist seems forced to argue that there is no design in nature and that the exquisite architecture of life is some sort of illusion. This approach fails as common-sense argument, but more importantly, it fails as science. There is indeed a "design" to living systems—but it is not the top-down design that would be produced by an architect or craftsman; it is a bottom-up design that is the result of evolution.

We should begin our deconstruction of the design argument by pointing out the obvious—that living systems do show a correlation between structure and function that a reasonable person might indeed call "design." The structural biologist David DeRosier (1998) acknowledged this point exactly when he reviewed the organization of the bacterial flagellar motor, stating that "… more so than other motors, the flagellum resembles a machine designed by a human." The question, of course, is whether this resemblance implies the sort of intelligent agent that the advocates of ID would suggest. It does not, as Bruce Alberts has pointed out (Alberts 1998). Among the questions he would have scientists ask about "protein machines," Alberts wrote, was "to what extent has the design of present-day protein machines been constrained by the long evolutionary pathway through which the function evolved, rather than being optimally engineered for the function at hand?" I believe that Alberts was on to something. As his words suggest, biological complexity can indeed show "design," but a design revealed and constrained by the process of evolution itself.

In his book, *Your Inner Fish*, paleontologist Neil Shubin addressed the issue of biological design at the physiological level by bringing evidence together from fossils, developmental biology, and molecular genetics (Shubin 2008). There is indeed a design to the body, as Shubin demonstrated, a design reflecting the evolutionary history of our species. Our skeletal structure results from a modification of the fish body plan; our muscles are laid out in segments that reflect the blocks of tissue associated with each segment of the vertebrate body, and even the complex and confusing pathways of cranial nerves can be explained by comparison with our evolutionary relatives.

Even proteins can fairly be said to possess a design, yet once again, that design makes sense only in evolutionary terms. This fact was brilliantly exploited in a study that used evolutionary relationships between present-day organisms to reconstruct the actual gene for an ancestral corticoid receptor existing some 450 million years ago (Ortlund et al. 2007). Using the comparative structures of two different receptor proteins, one that binds glucocorticoid and another specific for mineralocorticoid, they reconstructed the ancestral receptor from which both are derived. The comparative study not only proved the value of exploiting the evolutionary design of protein structures, but also provided new insights into the mutational pathways by which gene duplication generates new biochemical systems with novel functions.

In short, the scientific community can make the case for evolution by accepting the concept of design and then demonstrating that the design of living things is an evolutionary one. One element of the power of this approach is that it clearly rises above the appeal to ignorance inherent in ID. Another equally important aspect is that it does not require the scientific specialist to solve the evolutionary origins of every conceivable structure, pathway, or organ. By demonstrating that well-understood cases display clear evidence of their evolutionary ancestry, the point is made and it is made convincingly.

DARWIN IN THE BLOOD: A CASE STUDY

An example of this approach can be fashioned from one of the arguments used by the ID movement itself: the supposed "irreducible complexity" of the vertebrate blood-clotting cascade (Fig. 1). In humans, more than a

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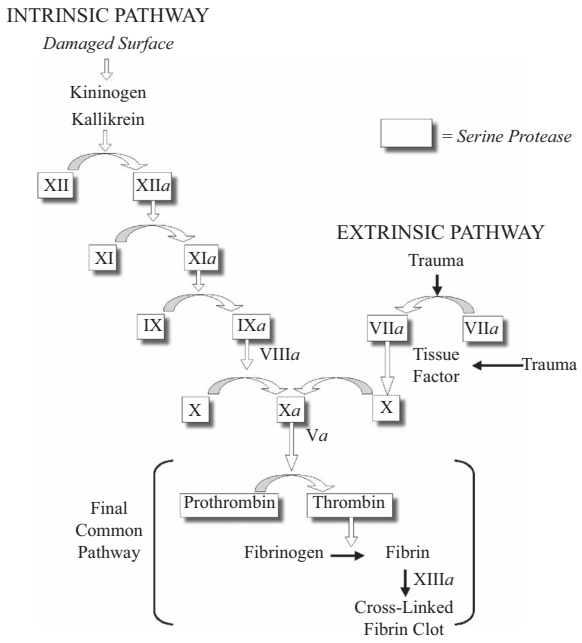

Figure 1. A simplified representation of the major components of the blood-clotting pathway. Each of the components of the pathway represents a "clotting factor," a portion of the pathway that triggers the next step. The horizontal arrows represent conversion of a factor from its inactive form to the active form, and the vertical arrows indicate the factors that trigger such conversions. The final result of the pathway, shown at the bottom, is the formation of a clot of cross-linked fibrin proteins that stops bleeding. Intelligent design (ID) contends that the pathway cannot work until all of these factors are in place, so it could not have been produced by a gradual step-by-step evolutionary process. This contention is refuted by recent research on the evolution of clotting factors.

dozen proteins and cofactors are involved in the clotting process, and serious disorders result when any of these components is missing or damaged.

Michael Behe, a leading advocate of ID, discussed the clotting system in a chapter he helped to write for the widely distributed ID textbook *Of Pandas and People*:

> However, biochemical investigation has shown that blood clotting is a very complex, intricately-woven system containing a score of interdependent protein parts. The absence or defective operation of any of several of these components will cause the system to fail, and blood will not clot at the proper time or at the proper place (Davis and Kenyon 1993, p. 141).

Consider the nature of this argument: If each and every part of the system must be present simultaneously for blood to clot, the clotting system could never have been produced by gradual step-by-step evolution. It is indeed "irreducibly complex" and therefore unevolvable. If Darwinian evolution could not have produced it, what could have? The answer, according to ID enthusiasts, must be intelligent design. Behe (1996) made this point even more directly in a popular book on intelligent design, *Darwin's Black Box*. As he wrote, "…in the absence of any of the components, blood does not clot, and the system fails" (p. 86) and "Since each step necessarily requires several parts, not only is the entire blood-clotting system irreducibly complex, but so is each step in the pathway" (p. 87).

The blood-clotting system provides a perfect example of how to make a case for ID. We find a system that is not only complex, but *irreducibly* complex, a system in which the absence or loss of a single component would destroy function. Such a system would not just be difficult to evolve, it would be impossible. Darwinian evolution, in the words of Darwin himself, requires "numerous graduations" on the way to a complex system, and every one of those gradations must be advantageous—they all have to work. The irreducible complexity of blood clotting, however, shows that absence of even a single part of the pathway would be fatal. Find as many fossils as you like, one might say, but it does not matter if evolution cannot clot the blood.

As with other claims made against evolution, the most effective way to deconstruct "design" is to take the ID argument seriously. In this case, it would involve investigating ID's bold prediction that *all* of the clotting components must be present for the system to function. Unfortunately for the ID argument, this prediction is now known to be wrong.

A report from the 1960s suggested that whales and dolphins lacked one of the clotting factors (Robinson et al. 1969), but ID advocates could easily have explained that away as the unreliable product of research in the premolecular age. However, the loss of factor XII was confirmed (Semba et al. 1998) in a study demonstrating that pseudogene conversion accounts, in molecular terms, for the factor's absence from the cetacean bloodstream. In 2003, the case against irreducible complexity was further strengthened when Russell Doolittle's laboratory demonstrated that the genome of *Fugu*, the puffer fish, lacks three of the clotting factors but nonetheless has a functional clotting system (Jiang and Doolittle 2003). More recently, the same lab has studied the lamprey genome and discovered that lampreys lack even more of the components of the supposedly "irreducible complex" clotting system (Doolittle et al. 2008). These investigators wrote, "In summary, the genomic picture presented here suggests that lampreys have a simpler clotting scheme than later diverging vertebrates. In particular, they appear to lack the equivalents of factors VIII (or V) and IX, suggesting that the gene duplication leading to these factors, synchronous or not, occurred after their divergence from other vertebrates."

The existence of a partial pathway that not only has a useful function, but also performs what we might call the final function (blood clotting) demonstrates beyond any doubt that complex pathways can be built up a few steps at a time from simpler ones. Furthermore, Doolittle's lab has also shown that the genome of the sea squirt *Ciona intestinalis*, which does not have functional clotting factors, nonetheless contains copies of nearly all of the protein domains from which those factors are built (Jiang and Doolittle 2003). In effect, we find the raw materials for clotting exactly where evolution tells us they should be, in the last group of organisms to split off from the vertebrates before blood clotting appeared. By taking the claim of "design" seriously, we discover that even one of the ID

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movement's favorite examples was clearly the product of evolution. The clotting system is but one of many cases to which this approach can be applied.

DARWIN'S GENOME

In the popular imagination, the principal evidence for human evolution is thought to come from the fossil record of prehuman primates. Although the evidence is indeed compelling, an even more powerful case can be made from the record of human ancestry in our own genome. Just 2 weeks before the Dover ID trial was called to order, researchers added to this evidence the DNA sequence of the chimpanzee. The utility of this new information in establishing the validity of evolutionary theory could hardly be understated. As the authors of the lead article on this breakthrough observed,

> More than a century ago Darwin and Huxley posited that humans share recent common ancestors with the African great apes. Modern molecular studies have spectacularly confirmed this prediction and have refined the relationships, showing that the common chimpanzee (*Pan troglodytes*) and bonobo (*Pan paniscus* or pygmy chimpanzee) are our closest living evolutionary relatives (Mikkelsen et al. 2005).

To bring the weight of this evidence into the courtroom, we chose a simple example that provides a direct test of the hypothesis of common ancestry for our species. As any biology student knows, we humans normally have 46 chromosomes. If we do indeed share common ancestry with organisms such as the gorilla, orangutan, and chimpanzee, an interesting question must be answered. All of the great apes have 48 chromosomes. If we really do share a common ancestor with these species, then what happened to that extra pair of chromosomes?

One might suggest that in the lineage leading to our species, a pair of chromosomes simply was lost or discarded. Unfortunately, in genetic terms, this is not a realistic suggestion. There are so many important genes on every primate chromosome that the loss of both members of a chromosome pair would be fatal. The only realistic possibility is that two different primate chromosomes were accidentally fused into one at some point in human evolution. Chromosome fusions of this sort are not at all uncommon and would indeed have reduced the chromosome number from 48 to 46. But if this sort of fusion did take place in the recent past, it should have left unmistakable evidence behind. Somewhere in the human genome there should be a chromosome still bearing the marks of that fusion, and therein lies an opportunity to put the hypothesis to a scientific test.

What would a fused chromosome look like? Telomeres, the tips of chromosomes, contain unique, repeating DNA sequences that are especially easy to recognize. If two chromosomes fused into one, the fusion site would contain telomere DNA sequences where they simply do not belong, on either side of the fusion site. In addition, each chromosome also contains a region known as the centromere where chromosomes attach to the machinery that separates them during cell division. Centromeres likewise have distinctive DNA sequences that enable them to be easily identified. If one of our chromosomes had indeed been produced by the fusion of two others in the recent past, that chromosome should contain telomere sequences near the middle of the chromosome and should also contain two centromere sequences.

Now the task gets interesting. We can scan the human genome and see if any of our chromosomes fit this very precise description. If we do not find such a chromosome, the hypothesis of common ancestry for our species might be cast into serious doubt. But if we do find a fused chromosome, a specific evolutionary prediction is fulfilled. So, which is it?

The answer—provided in dramatic detail by the human genome project—is that evolution got it exactly right (Hillier et al. 2005). The solution is found in human chromosome 2, which does indeed contain telomere DNA sequences at the fusion point and carries the remnants of two centromere sequences, as illustrated in Figure 2. One of these is still active in humans and corresponds to the centromere for chimp chromosome 12. The other has been inactivated, which makes the fused chromosome more stable during cell division, but it is still recognizable as corresponding to the centromere from chimp chromosome 13 (Hillier et al. 2005). The conclusion from these data is unavoidable: We do indeed share a common ancestor with these species, a common ancestor that possessed, in the recent past, 48 chromosomes. No fingerprint left at the scene of a crime was ever more decisive than this genetic evidence. We evolved.

CONCLUSIONS

For science, I believe that the collapse of "intelligent design," so evident in the Dover trial, carries a clear

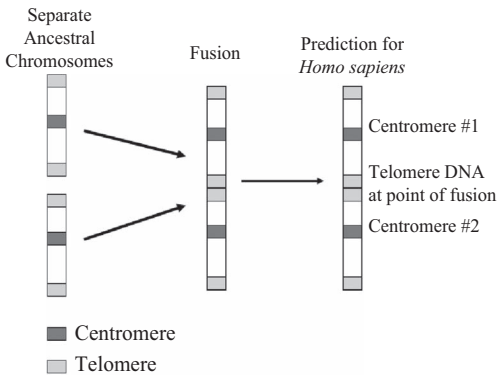

Figure 2. An accidental fusion between two chromosomes could explain why humans possess 46 chromosomes, rather than 48 as do the great apes. However, such a fusion event would leave distinct marks in the new chromosome. Chromosomes contain recognizable regions at their tips known as telomeres and regions near their midpoints called centromeres. If two complete chromosomes fused together, telomere sequences would be expected to remain near the fusion site. In addition, the fused chromosome would be expected to carry two centromeres. The second human chromosome displays each of these predicted elements, providing strong support for the evolutionary hypothesis of common ancestry.

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meaning, i.e., that the process of science should be respected. Challenges to evolution—or any other scientific theory—are very much within the scope and tradition of science. If the practitioners of ID actually seek to displace evolution scientifically, they need only to produce the data to support their case, to carry the fight to the scientific community in a way that would win the battle of evidence in the free marketplace of scientific ideas. Instead, they have consistently rejected that route in favor of public relations activity and the generation of political support. Scientifically, it should be obvious that no idea deserves a place in the classroom that it cannot win for itself on the basis of the evidence. The lesson for science is that organized attempts to skirt the scientific process of debate and peer review can and must be resisted. Not just because they happen to be wrong, as is the case with ID, but because they subvert the very process of science itself.

One of the most effective scientific responses, as I have suggested, is to defend science by deconstructing the design argument. The structure, composition, and organization of living systems do indeed reveal a kind of design, but it is a living architecture produced by the evolutionary process itself. Science is necessarily incomplete, and the opponents of evolution will always be able to point to unsolved problems as evidence that the evolutionary narrative is incomplete as well. But these challenges should be seen as opportunities. We make the best case for science when we show how evolution accounts for the realities of living systems in a way that pretenders such as ID simply cannot. If we do this effectively, in the final analysis, the vast majority of Americans may come to realize, as Charles Darwin did, that there is indeed beauty, wonder, and grandeur in the evolutionary view of life.

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