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Natural Selection, Irreducible Complexity, and the Bacterial Flagellum: A Contrarian Approach to the Intelligent Design Debate

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By David Crump*

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This article concerns a subject about which a great deal has been said, and over which many people have drawn battle lines.[1] I believe, however, that I offer a different view. I myself believe that natural selection explains the origin of species. I think it is improbable that theories of irreducible complexity and intelligent design, which I shall explain and discuss here,[2] provide answers. I also believe, however, that the introduction of these alternate theories in public school biology classes would accomplish desirable purposes—and that it could be accomplished consistently with the Constitution.[3]

I. INTRODUCTION: THE BACTERIAL FLAGELLUM AND TWO VIEWS OF ITS ORIGINS

There is a wonderful puzzle presented by the bacterial flagellum, that wavy appendage that supplies locomotion for some microorganisms.[4] Originally, scientists thought that bacteria moved by whipping their flagella back and forth.[5] In fact, flagellum derives from the Latin word for "whip."[6] More recent observations, however, show that the flagellum for some organisms is a corkscrew, and it does not sway back and forth. Instead, it turns on a wheel that is embedded in the microorganism.[7] If one pictures a

1. For an introduction to the controversy and the respective positions, see, e.g., LESLIE C. GRIFFIN, LAW AND RELIGION: CASES AND MATERIALS 563–618 (2006). For a treatment that explores the subject in a scholarly way but concludes, as this article does, that teaching irreducible complexity and intelligent design in public schools could be accomplished constitutionally, see Johnny Rex Buckles, *The Constitutionality of the Monkey Wrench: Exploring the Case for Intelligent Design*, 59 OKLA. L. REV. 527 (2006).

2. *See infra* notes 23–46 and accompanying text.

3. *See infra* Parts II–V; *see also* Buckles, *supra* note 1 (expressing a similar conclusion, but with exploration of different issues).

4. *See* Wikipedia, Flagellum, http://en.wikipedia.org/wiki/Flagellum (last visited Sept. 28, 2008).

5. *Id.*

6. *Id.*

7. *See, e.g., id.*; Access Research Network Molecular Machines Museum, *The Bacterial Flagellum*, http://www.arn.org/docs/mm/flagellum_all.htm (last visited Sept. 28, 2008) (describing the views of Michael Behe, including support for theories of irreducible complexity); Ian Musgrave, Evolution of the Bacterial Flagella, (Mar. 17, 2000), http://www.health.adelaide.edu.au/Pharm/Musgrave/essays/flagella.htm (providing a theory, instead, of evolution). As Musgrave points out, "there is no 'the' bacterial flagella." *Id.* Flagella of eubacteria and archebacteria are superficially similar, but in fact they are composed of different, non-homologous proteins. *Id.* The difference suggests that the two systems probably evolved independently, through distinct pathways, after the eubacterial/archebacterial evolutionary split. *Id.* Even within eubacteria, there are distinct forms. *Id.* The variation in types of flagella is not determinative in most aspects of this article, however, and it refers to "the" flagellum as including flagella generally except when distinctions

bear, a horse, or a whale with locomotion supplied by wheels buried in its torso, one can imagine the surprise that bacteriologists must have felt when they learned how the flagellum works.

But actually, the mechanism of the flagellum is even stranger and more complex than this. The bacterium needs something to turn the wheel to which its corkscrew is appended. And it has a connection to make it turn, because the wheel is serrated, and it fits another wheel in a gear-like system.[8] The mechanism needs lubrication, as well as a system for removing impurities, and the bacterium is equipped with both.[9] The flagellum needs a propeller, and it has one: the corkscrew.[10] The driving wheel needs a source of circular motion, and it is there: a motor that uses hydrogen ion flow across a living gradient.[11] The bacterium also can boast dozens or even hundreds of other coordinated parts, such as bearings, bushings, and universal joints.[12]

The reason that the flagellum is a puzzle is that our prevailing theory of the origin of species involves natural selection. This phenomenon is the mechanism for a theory sometimes referred to as evolution,[13] but this label should not be taken too literally because "evolution" seems to suggest steady, smooth, and purposeful change. Natural selection is not necessarily steady, smooth, or purposeful.[14] The essence of the theory can be expressed in a single sentence: random genetic mutations in discrete characteristics produce individuals that propagate at different rates, and those that survive and propagate most plentifully in the existing environment are "naturally selected."[15] Thus, species change is accomplished by small, sudden, and

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among types are necessary. *Id.*

8. Musgrave, *supra* note 7, at 2–4.

9. *Id.*

10. *Id.*

11. *Id.*

12. *Id.* Flagella and their drives are machines of "staggering complexity, with dozens or even hundreds of precisely tailored parts." Access Research Network Molecular Machines Museum, *supra* note 7.

13. *See* Wikipedia, Evolution, http://en.wikipedia.org/wiki/Evolution (last visited Sept. 28, 2008). The subject is explored in many different high school and college texts. *See, e.g.*, GEORGE JOHNSON & PETER RAVEN, BIOLOGY ch. 13 (2004); WILLIAM K. PURVES ET AL., LIFE: THE SCIENCE OF BIOLOGY chs. 1, 21–22 (6th ed. 2001); PETER H. RAVEN & GEORGE B. JOHNSON, BIOLOGY ch. 1 (2d ed. 1989).

14. There are different kinds of evolution, corresponding to different mechanisms. *See* Wikipedia, Evolution, http://en.wikipedia.org/wiki/Evolution (last visited Sept. 28, 2008). "Directional" selection is the shift in average traits over generations: for example, organisms slowly growing taller. *Id.* But "disruptive" selection results from change in biota such that extreme traits provide a new survival or procreative advantage, and it produces more sudden change. *Id.* There also is a type of "stabilizing" selection, which tends toward uniformity. *Id.*

15. *See id.* More precisely, variations occur from three mechanisms: natural selection, genetic drift (the alteration in allele frequency in progeny caused by random sampling of genes), and gene flow (the transfer of genes within and between different populations). *Id.* The latter two

non-purposeful steps. Most mutations are dysfunctional and lead to premature death.[16] It is only the occasional, rare difference that improves survival and enhances propagation enough to become a lasting adaptation.[17] Therefore, the process occurs in tiny increments, over enormous numbers of individuals.

The problem posed by the bacterial flagellum is that it takes real imagination to see how the entire mechanism could have resulted from a process of natural selection.[18] Darwin himself observed that his theory would fail if contradicted by the identification of complex systems that were incapable of being created through discrete steps.[19] At first blush, the bacterial flagellum might seem to embody exactly the falsifying instance that Darwin was talking about. Its interlocked parts might seem too diverse, too complex, and too coordinated to have resulted from a sequence of random changes. Furthermore, it is not easy to postulate a means by which these tightly fitting elements could have sprung into existence independently.[20] It might seem that the wheel would be useless without its serrations. Or without the driving gear. Or without the flagellum, or without its corkscrew propeller, or without the lubricating and self-cleaning systems that support them.[21] Thus, the notion that the entire set of parts appeared coincidentally but simultaneously from a large number of random mutations all occurring at once seems improbable, and the idea that the parts

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mechanisms are related to Mendelian heredity—the genetic influence of a parent upon the genes of offspring—which, during the 1930s, combined with the theories of Charles Darwin to produce the modern evolutionary synthesis. *Id.*

16. *Id.*

17. *Id.*

18. *See generally* MICHAEL J. BEHE, DARWIN'S BLACK BOX: THE BIOCHEMICAL CHALLENGE TO EVOLUTION 72–73 (1996) (using the flagellum as an example in support of the irreducible complexity theory). "Darwinian theory has given no explanation for the cilium or flagellum. The overwhelming complexity of the swimming systems push us to think it may never give an explanation." *Id.* at 73. In arguable contradiction of this statement, however, Darwinian theory has proposed possible answers. *See supra* note 7 and accompanying text; *see infra* note 29 and accompanying text.

19. *See* CHARLES R. DARWIN, THE ORIGIN OF SPECIES BY MEANS OF NATURAL SELECTION, OR THE PRESERVATION OF FAVOURED RACES IN THE STRUGGLE FOR LIFE 158–60 (Bantam Books 1999) (1859).

20. It is not easy a priori, perhaps, but it is important to emphasize that it has been done, and reasonably promptly after the challenge arose. *See infra* notes 29–30 and accompanying text.

21. Arguably, however, the key phrase here is, "It might seem." There is a flaw in reasoning from this inference. An adaptation naturally selected because it provides an advantage through one discrete function may undergo further mutation and thereby adapt to serve another function, and thus it may evolve into a mechanism more complex than would be likely to result from a single evolutionary step. This phenomenon is referred to as "exadaptation." *See infra* note 165 and accompanying text. It provides a powerful counter-theory to models of irreducible complexity.

came into being sequentially and independently might seem almost as improbable, because separately they could not accomplish what the combined mechanism can do. The theory fails unless the separate parts, when they appeared, could have enhanced the survival and reproduction of the bacterium.[22] Or at least, this reasoning describes how the problem might appear upon first examination.

The less widely accepted concept of "irreducible complexity"[23] is a controversial alternative to natural selection, and its fundamental idea can be stated with equal simplicity. Advocates of this model argue that some systems in living organisms exhibit such irreducible complexity that they cannot have been produced by the coincidence of multiple random mutations.[24] They must instead be the product of purposeful processes, or in other words, of intelligent design.[25] Proponents of this argument illustrate it by examples such as the bacterial flagellum.[26] Irreducible complexity theorists claim that this multi-part mechanism contradicts the assumptions underlying natural selection as an exclusive theory and requires the additional inference of a purposeful element in the origin of species, at least to explain some phenomena.[27]

Debates between proponents of irreducible complexity and adherents to natural selection tend to end in indeterminacy. Irreducible complexity advocates confront natural selectioners with examples such as the bacterial flagellum, arguing that these phenomena are not easily explainable by Darwin's theory.[28] Bacteriologists have, in fact, responded to the irreducible complexity criticism by proposing pathways by which natural selection of the separate parts of the flagellum could have proceeded.[29] But there is as yet no consensus, and we are a long way from the kind of testing and proof

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22. *But see supra* note 21 (debunking this reasoning).

23. The overall theory related to this idea is often described as "intelligent design," although this label is more controversial. *See* Wikipedia, Intelligent Design, http://en.wikipedia.org/wiki/Intelligent_design (last visited September 28, 2008). "Irreducible complexity" is Michael Behe's proposed evidence that evolution alone is an insufficient theory. *See* BEHE, *supra* note 18, at 72–73. In this article, I use both "intelligent design" and "irreducible complexity" to refer to the same groups of theories on the grounds that "irreducible complexity" is the less objectionable term, a term that is closely identified with intelligent design, and arguably, if it is accepted, implies its viability. *See infra* Part V.C.2.

24. *See* BEHE, *supra* note 18, at 72–73.

25. *See id.*

26. *See id.*

27. *See id.*

28. *See id.*

29. *See, e.g.*, Musgrave, *supra* note 7. Musgrave proposes "a possible scenario" for evolutionary pathways, in which "a secretory system arose first . . . which was the common ancestor of [a type of] secretory system, and the flagellar system[,]" after which, a crude flagellum appeared as part of the secretory structure, and finally, the motor evolved from "an ion pump which was doing something else . . . ." *Id.*

that would enable natural selection advocates to claim that the puzzle is solved.[30] Thus, the answer of natural selectioners boils down to the suggestion that, some day, advances in observation certainly will enable us to explain these unknowns.[31] Among themselves, irreducible complexity adherents might see the argument of some of their opponents that "your theory is wrong, even if we can't explain the data yet"[32] as ranking with the arguments of Galileo's detractors, who used epicycles to explain planetary retrogression.[33] In any case, one might think that the criticisms implied by irreducible complexity theory would be recognized as valuable.

But in this, one would be quite wrong. Instead, the enemies of irreducible complexity have managed to drive it out of the public square.[34] Their weapon, unfortunately, has not been the kind of debate that I have just described. Instead, they have used the device of hanging the albatross of

30. For a theory contrasting Musgrave's, see N. J. Matzke, Evolution in (Brownian) Space: A Model for the Origin of the Bacterial Flagellum (Nov. 10, 2003), http://www.talkreason.org/articles/flag.pdf (proposing a simpler pathway based on the possibility that very crude motility may have offered Darwinian advantages).

31. For example, Edward O. Wilson, Harvard's Pellegrino University Professor Emeritus, debunks theories based on irreducible complexity by asserting that although "[t]here are some phenomena that have not yet been explained" (such as the bacterial flagellum), nevertheless, the "default . . . steadily shrinks as the science of biology expands." Edward O. Wilson, *Intelligent Evolution: The Consequences of Charles Darwin's "One Long Argument,"* HARVARD MAGAZINE, Nov.–Dec. 2005, at 31–32. The difficulty with this reasoning is that it assumes that the default will "shrink" in ways predicted by existing theories of biology rather than those hypothesized by those with whom Wilson disagrees.

32. *See supra* note 31; *see also* Daniel L. Hartl, *Better Living Through Evolution: The Science of Novelty and Complexity in Life Forms*, HARVARD MAGAZINE, Nov.–Dec. 2005, at 22–27 (debunking theories of irreducible complexity as a "sly dissimulation" created only to "dodge" holdings in Supreme Court cases, even though "we have limited experimental data" on the formation of new species).

33. *See* Wikipedia, Galileo Galilei, http://en.wikipedia.org/wiki/Galileo_Galilei (last visited Sept. 28, 2008). Galileo Galilei advocated the heliocentric view of the solar system, i.e., that the earth traveled around the sun. *Id.* Pope Urban and many Catholic Church officials instead accepted Aristotelian geocentricism (a stationary earth) from their interpretations of Biblical Scripture. *Id.* Ultimately, the church tried Galileo for heresy, convicted him, required him to recant, banned his offending book, and sentenced him to imprisonment (later commuted to house arrest). *Id.* But the planets sometimes changed direction and backed up (retrogressed) in the sky, and this phenomenon suggested a flaw in the geocentric model. *See* DAVID CRUMP, HOW TO REASON ABOUT THE LAW: AN INTERDISCIPLINARY APPROACH TO THE FOUNDATIONS OF PUBLIC POLICY 309 (2001). Politically correct scientists tried to salvage the church's theory by postulating epicycles (the theory that planetary orbits traced circles traveling upon circles) to explain the phenomenon. *Id.*

34. *See, e.g.*, Kitzmiller v. Dover Area Sch. Dist., 400 F. Supp. 2d 707 (M.D. Pa. 2005) (granting declaratory judgment, an injunction, and attorney's fees against a school district that had required introduction of basic intelligent design ideas); GRIFFIN, *supra* note 1, at 617–18 (reporting the cancellation of a philosophy class—not a science class, but a philosophy class—that would have studied the comparisons among intelligent design, evolution, and other theories).

religion around the necks of irreducible complexity proponents, particularly when the theory has been accompanied by the natural inference of intelligent design.[35] The nub of the argument is that intelligent design facilitates a religious sort of philosophy, although it requires neither a deity nor any religion,[36] and that it originated from people and ideas that are religious,[37] although the same could be said of Newton's laws of motion.[38] Thus, the opponents of irreducible complexity argue that governmental accommodation of intelligent design is an unconstitutional establishment of religion. The argument of exclusivist natural selectioners is supported by the claim that intelligent design is unscientific,[39] as well as by the undeniable fact that irreducible complexity is not nearly so complete a phenomenology as natural selection.[40] Ironically, although the Supreme Court has repeatedly proclaimed that there is "no such thing as a false idea,"[41] the American Civil Liberties Union has been particularly effective in using the courts to suppress irreducible complexity theory by labeling it as a false idea.[42]

I myself believe that natural selection is overwhelmingly supported by the evidence. I believe that it is a valid, predictive, and extraordinarily useful scientific theory. Although I dislike the rhetoric of scientists who refer to Darwin's themes as "fact,"[43] simply because I think such statements are arrogant and misleading, I would say that, if ever there were a scientific theory so impregnable as to be described as fact, natural selection would

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35. *See supra* note 34.

36. "The designer is seldom specified, but . . . it is most certainly not Satan and his angels, nor any god or gods conspicuously different from those accepted in the believer's faith." Wilson, *supra* note 31, at 31. Unfortunately, being Emeritus at Harvard does not ensure against sophistry. Perhaps the "designer" is not "specified" because identifying a precise designer is not a part of the theory (and is unknown). Or perhaps there is a design without an identifiable designer: a frequent occurrence in nature, as when a symmetrical normal curve results from random events or when the periodic table of the elements shows a clear design. Or perhaps, as in the case of Michael Behe's theory, irreducible complexity is a hypothesis from data perceived as poorly explained by evolutionary theory. *See* BEHE, *supra* note 18, at 72–73.

37. The inference of unconstitutionality often is based on the support by religious people for the teaching of intelligent design. *See supra* note 34. This basis is unsound. *See infra* Part V.C.1.

38. "In his own lifetime, Newton wrote more on religion than he did on natural science." Wikipedia, Isaac Newton, http://www.en.wikipedia.org/wiki/Isaac_Newton (last visited Sept. 28, 2008). Furthermore, Newton did not follow recognized scientific methods of today but derived his conclusions from a priori logic within the context of his religious beliefs. *Id.*

39. *See Kitzmiller*, 400 F. Supp. 2d at 734.

40. *See* Wilson, *supra* note 31, at 31–32 (asserting that irreducible complexity theory is based on a "default" of knowledge that "steadily shrinks as the science of biology expands").

41. *E.g.*, Gertz v. Robert Welch Inc., 418 U.S. 323, 339 (1974); Ollman v. Evans, 471 U.S. 1127, 1129 (1985) (Rehnquist, J., dissenting).

42. *Kitzmiller*, 404 F. Supp. 2d at 707. The ACLU represented the plaintiffs in *Kitzmiller* and successfully took the position that the assertion of any scientific basis for intelligent design was a false idea. *Id.*

43. *See, e.g.*, Wilson, *supra* note 23, at 31 (asserting that biologists "are unanimous in concluding that evolution is a *fact*" and criticizing those who refer to it as a theory).

qualify. I find natural selection a more persuasive explanation for the flagellum than I do the intelligent design proposition of irreducible complexity.[44] But I also believe that refusing to discuss contrary hypotheses is a poor way of providing answers to difficult questions. Minority theories, marginal theories, even improbable theories, can pose questions that encourage mainstream discoveries.[45] In any event, I do not see irreducible complexity or intelligent design as inherently religious, or at least, I will argue in this article that it is no more religious than natural selection is itself a religious doctrine.[46] In short, I believe that irreducible complexity theory should be considered together with natural selection in public schools in a way that minimizes the overtly religious content of both.

The first part of this article will examine the claim that intelligent design is "unscientific."[47] This issue requires consideration of the unanswerable question—"What is science?" It should be added, however, that the constitutional question is not whether irreducible complexity is "scientific," but whether it is "religious" in ways that create an Establishment Clause violation. Still, the claim that irreducible complexity and intelligent design are unscientific underlies some of the attacks on these theories, and the proposition is related to the question whether teaching them can serve secular purposes. Therefore, the science-or-not issue is relevant even though it is not the ultimate question.

Next, the article will confront the question whether the teaching of irreducible complexity achieves secular purposes.[48] The article will conclude that there are such purposes and that they include suggesting avenues for scientific inquiry, aiding the formulation of hypotheses, and, in short, spurring development of mainstream evolutionary thought.[49] The list of secular purposes also will include providing insights into the philosophy of science that cannot be supplied as well by other ideas; exploring epistemology, or the nature of evidence and proof in assessing knowledge; teaching methods of debate that analyze mutually inconsistent arguments; and, paradoxically, introducing a greater neutrality toward religion than can be achieved by the teaching of Darwinism alone, which arguably results in inculcating religious ideas as well as scientific ones.[50] Then, too, censorship

44. *See infra* Part VI.
45. *See infra* Part III.B.
46. *See infra* Part V.A.
47. *See infra* Part II.
48. *See infra* Part III.
49. *See infra* Part III.
50. *See infra* Part III.

of the irreducible complexity critique can have a spillover effect, and therefore, the article will explore the possibility that avoiding censorship of other valuable discussion is a valid secular purpose.[51] Finally, mature acceptance of natural selection, as well as the ability to defend it in debate against intelligent design, requires at least a minimal understanding of the criticisms implied by irreducible complexity theory.[52] In other words, the article will conclude that students should understand irreducible complexity in order to be able to argue against it and (if they so decide) to reject it.[53]

The third section of the article will outline various approaches to the Establishment Clause, which is the principal basis of legal objections to the consideration of irreducible complexity theory in public schools.[54] The *Lemon* test, the endorsement and coercion tests, and the accommodation doctrines will all be dealt with only briefly, however, because these concepts have been well developed elsewhere.[55] Then, the fourth section of the article will discuss whether the secular purposes I have suggested can be achieved without endorsement of or excessive entanglement with religion.[56]

The final section will contain some of my conclusions.[57] I believe that the discussion in public schools of irreducible complexity can be as independent of religious content as the teaching of natural selection can be. This contrarian view does not require that the two concepts be provided equal time or anything like it, or that they be treated as equally scientific, valuable, or valid. If I were a high school biology teacher with freedom to choose, I myself would devote most of the effort to natural selection, with irreducible complexity touched upon as an alternate idea or as a criticism to which evolutionary scientists have proposed answers. The precise mixture would become a question of educational policy. My article will conclude, however, that the non-religious introduction of irreducible complexity and intelligent design into the teaching of natural selection would be both constitutional and desirable.[58]

II. IS INTELLIGENT DESIGN "SCIENTIFIC"—AND WHAT DOES THIS QUESTION MEAN?

There is no single theory of science. Instead, there is a variety of views about what it means to call an assertion "scientific." One of the positive

51. *See infra* Part III.
52. *See infra* Part III.
53. *See infra* Part III.
54. *See infra* Part IV.
55. *See infra* Part IV.
56. *See infra* Part V.
57. *See infra* Part VI.
58. *See infra* Part VI.

benefits of considering irreducible complexity is that the theory seems more scientific under some definitions than under others. In fact, irreducible complexity is an ideal candidate for illustrating several possible answers to the question—"What is science?"

For empiricists or positivists, science depends upon empirical observation. To put the idea simply, if a proposition does not involve the testing of data, in this view, it is not science.[59] But then, there also is the rationalist view, which holds that science depends on theory.[60] Under this approach, if it does not involve a unifying, rationalizing theory, it is not science.[61] Newton deduced his mechanics as a theoretical exercise without experiment or hypotheses, and his famous statement, "Hypotheses non fingo," (i.e., "I don't generate hypotheses") shows the rationalist origins of his monumental contributions to physics.[62] A third approach sees science as allowing for quantitative prediction. If you cannot do the mathematics, this view would hold, you do not have anything scientific.[63] This is a simplistic sketch of the three approaches, but it will do, as a beginning, for showing that there are different definitions of science.

Even a superficial examination of these philosophies of science, however, shows that none is viable alone. The strictest empiricist would regard a number of data points as scientific, but the smooth line that joins them together into a theory is not scientific. Strict empiricism would say that the data points may themselves have been empirically observed, but each one of the infinite points between them is not yet part of the observed data. We cannot know whether the smooth line that we interpolate represents anything real. And so, under the view of an empiricist who excludes the possibility that a theory can be inferred from incomplete information, the clump of data that we have collected is just that—a clump of data—and we cannot make inferences from it. Thus, the strict empiricist turns out to have nothing, unless there is a concession that some of what the rationalist demands is needed. On the other hand, theory without

59. *See* CRUMP, *supra* note 33, at 301–02; *see also* DONALD PALMER, DOES THE CENTER HOLD? AN INTRODUCTION TO WESTERN PHILOSOPHY chs. 2–3 (2d ed. 1996) (explaining the rationalist and empiricist philosophies); GUNNAR SKIRBEKK & NILS GILJE, A HISTORY OF WESTERN THOUGHT: FROM ANCIENT GREECE TO THE TWENTIETH CENTURY chs. 10, 12, 26 (7th ed. 2000). Much of what is written in this section overlaps one of my earlier articles, but it is used here in a different way. *See* David Crump, *The Trouble with* Daubert-Kumho*: Reconsidering the Supreme Court's Philosophy of Science*, 68 MO. L. REV. 1 (2003) [hereinafter Crump, *The Trouble with* Daubert-Kumho].

60. *See* CRUMP, *supra* note 33, at 302–03.

61. *Id.*

62. *Id.* at 303. Literally, "I don't touch [upon] hypotheses."

63. *Id.*

observation puts us into the realm of either pure logic or fantasy. No matter how beautiful the calculations made by a rationalist may be, they are disconnected from the physical universe if they do not correspond to any observation. In summary, without the ability both to conjecture about theories on the one hand and to test or verify them by observation on the other, none of the approaches alone allows us to do anything with the theories we generate or data that we collect.

Different philosophers put different spins on the three components. Thus, there is no universally accepted definition of science. The question—"What is science?"—sounds easy to answer, but in fact it is difficult.

A. Falsificationists, Verificationists, and Pragmatists

1. Karl Popper's "Falsification" Approach: A Narrow (Perhaps Too Narrow?) View of Science

The United States Supreme Court has bought heavily into the "falsificationist" definition of science put forward by Sir Karl Popper.[64] Popper's approach is narrow—so much so that it excludes many people whom we might readily describe as scientists. In *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, the Court based its criteria for admissibility of scientific evidence on the statement that "[s]cientific methodology today is based on generating hypotheses and testing them to see if they can be falsified; indeed, this methodology is what distinguishes science from other fields of human inquiry."[65] The Court justified this view by quoting Popper's statement that "the criterion of the scientific status of a theory is its falsifiability, or refutability, or testability."[66] In considering the reliability of a statement or opinion, the *Daubert* Court stated as its primary criterion the characteristic of "falsifiability," or whether the underlying theory "can be (and has been) tested."[67]

In a concurring opinion, Justice Rehnquist modestly admitted that he did not understand what falsifiability meant.[68] He had a point because the rest of the Court certainly did not understand it. Under Popper's concept of falsifiability, the scientific status of a statement does not depend upon whether the statement already "has been" tested; falsifiability means only

64. *See* Daubert v. Merrel Dow Pharms., Inc., 509 U.S. 579, 593 (1993).

65. *Id.* at 593 (quoting ERIC GREEN & CHARLES NESSON, PROBLEMS, CASES & MATERIALS ON EVIDENCE 645 (1983)).

66. *Id.* at 593 (quoting KARL R. POPPER, CONJECTURES AND REFUTATIONS: THE GROWTH OF SCIENTIFIC KNOWLEDGE 37 (5th ed. 1989)).

67. *Id.*

68. *Id.* at 600 (Rehnquist, J. concurring).

that the proposed statement theoretically might be tested.[69] The broad implications of this idea are well developed. They have been discussed in college texts for more than twenty years. For example, Gunnar Skirbekk and Nils Gilje point out that Popper demanded falsifiability only "in principle," perhaps by means not yet available; means that might be invented in the future.[70] Any other approach would make a nonscientist of the theoretical physicist. It would also contradict the title of Popper's own book, the first word of which is "[c]onjectures."[71] After all, a major part of science is the formation of hypotheses. When hypotheses are created for the first time, of course, they have not yet "been tested." Consider the famous Michelson–Morley experiment, which used ingenious methods to measure the speed of light.[72] Before that time, theoretical physicists had deduced a great deal about the subject from known relationships. Surely, the absence of testing in those early days (until Michelson and Morley invented the means) did not demote those physicists into non-scientists.

Thus, if we can conceive of any way in which a particular statement might be testable in the future, this should be enough, under Popper's theory, to let us call the statement "scientific." In fact, even if we cannot conceive the way, but if testing of the statement might be possible someday by means that are as yet unknown, this possibility should be enough to make the statement "scientific." For example, Einstein and others have posited the existence of tachyons, particles that travel faster than light, as a consequence of reasoning based on the theory of relativity.[73] We have never tested this hypothesis because it is difficult to pin down a tachyon. But should this mean that the prediction of tachyons is unscientific? And if so, were all of the predictions from relativity, including those that since have been tested and corroborated, "unscientific" when Albert Einstein conceived them? Some day, we might be able to test tachyons. Thus, an appropriate understanding of Popper's theory would allow the tachyon conjecture to be treated as falsifiable because of the "someday" possibility.[74]

Popper's insistence upon the sole criterion of falsifiability raises deeper issues.[75] As is often the case with singular fixations, it does not fit all cases.

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69. POPPER, *supra* note 66, at 37.

70. SKIRBEKK & GILJE, *supra* note 59, at 429.

71. POPPER, *supra* note 66.

72. *See* ALEXANDER KOLIN, PHYSICS: ITS LAWS, IDEAS AND METHODS 840–41 (1950).

73. *See* Wikipedia, Tachyons, http://en.wikipedia.org/wiki/Tachyon (last visited Sept. 28, 2008).

74. *Cf.* SKIRBEKK & GILJE, *supra* note 59, at 429–33 (discussing the meaning of Popper's theories).

75. POPPER, *supra* note 66, at 37 (making this "the criterion" of science), *quoted in* Daubert v.

Thus, Skirbekk and Gilje point out that there is a whole range of statements that really should be considered scientific but that Popper's criterion excludes:

> [W]hat about the statement, "the average temperature on the surface of the earth when the human race is extinct, will be 70EC"? This statement is, in principle, not falsifiable since no one will be alive to falsify it (assuming that no other intelligent creatures replace human beings). But is this statement, then, cognitively meaningless, and not scientific? Scientists would probably be reluctant to draw this conclusion: they would hardly think that such statements are scientifically meaningless.[76]

A statement of this kind can be evaluated by various methods: by subtracting an estimate of human contributions from current average temperatures, for example, or by consulting prehistoric averages. But the statement cannot be falsified because it cannot be tested by experiment. Popper himself recognized this difficulty and later compromised with rationalism, even using the term "critical rationalism" to describe his own approach.[77] This concession arguably salvages the scientific status of fields such as logic, mathematics, or game theory, which are not falsifiable as a matter of principle.[78] But it is important to distinguish this brand of critical rationalism, which accepts inferences of various legitimate types, from Popper's other theory, with its single focus upon testability.

And this is only the beginning of the Supreme Court's misunderstanding of Popper. Although the Court used Popper's falsifiability criterion as one of the determinants of evidentiary reliability, Popper himself denied that science could ever become "reliable."[79] No matter how many times we observed a given phenomenon, said Popper, we could not confirm the theory that we have inferred from it; we could only "falsify" the theory if it failed to produce the expected outcome.[80] Science became, then, a body of knowledge composed of theories that had been discarded or falsified because experiments had resulted in contrary observations, and a remaining body of theories that had not been falsified but that had to be regarded as forever unconfirmed. Furthermore, according to Popper, the "corroboration" of a theory by non-falsification did not amount to "confirmation" because

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Merrel Dow Pharms., Inc., 509 U.S. 579, 593 (1993).

76. *See* SKIRBEKK & GILJE, *supra* note 59, at 429.

77. *Id.* at 429–31.

78. *Id.*

79. KARL POPPER, OBJECTIVE KNOWLEDGE: AN EVOLUTIONARY APPROACH 18, 22 (1972).

80. *Id.*

corroborating data represented its past performance only.[81] We could not assume that the theory would hold true in future experiments.[82] One might rely on the theory of gravity in deciding not to jump off the Empire State Building because of a commonsense prediction that one would fall, but no matter how many times one saw the theory escape falsification, one could not count gravity as a reliable, confirmed principle. Thus, ironically, the Supreme Court quoted Popper in support of a concept of reliability that Popper himself had rejected.

2. The Verificationists' Broader Approach: Science as Logical Inference, or Verification from Evidence

Popper's theory of science was an effort at "demarcation": the effort to define science in a way that distinguishes it from other types of inquiry or learning.[83] Other philosophers have denied the possibility of sharp demarcation. For example, "verificationists," such as Rudolf Carnap[84] and Hans Reichenbach,[85] consider science to include a "continuum" of different types of inferences from observation and evidence, although they emphasize empirical support. In other words, one can infer inductively that gravity works, and then deduce that jumping off the Empire State Building will cause a person to fall.

The verificationist approach sees all learning from observation and theorization as scientific, ranging from what might be called common sense to the most abstruse aspects of cosmology.[86] There is no one "scientific method," according to this approach. Instead, one reasons inductively and produces scientific hypotheses, which are verified or refuted by evidence.

Still others, such as Carl G. Hempel, see testing as important, along with Popper, but argue that other kinds of reasoning can be scientific too.

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81. *Id.*

82. *Id.*

83. *See* Susan Haack, *Trial and Error: The Supreme Court's Philosophy of Science*, 95 AM. J. PUB. HEALTH (Supp. 1) S67 (2005).

84. *See, e.g.*, RUDOLF CARNAP, THE CONTINUUM OF INDUCTIVE METHODS (1952); *see also* Wikipedia, Rudolf Carnap, http://en.wikipedia.org/wiki/Rudolph_Carnap (last visited Sept. 28, 2008).

85. *See, e.g.*, HANS REICHENBACH, THE RISE OF SCIENTIFIC PHILOSOPHY (1951); *see also* Wikipedia, Hans Reichenbach, http://en.wikipedia.org/wiki/Hans_Reichenbach (last visited Sept. 28, 2008).

86. *See* Haack, *supra* note 83, at S67. It should be added that this approach describes so-called "weak" verificationism, which accepts propositions that the evidence shows are probable. "Strong" verificationism accepts only propositions that are conclusive, but that approach is generally discredited.

Hempel also argued that confirmation results from repeated non-falsification, with the degree of confirmation depending upon the strength of the evidence.[87] Popper's falsifiability criterion, according to Hempel, "involves a very severe restriction of the possible forms of scientific hypotheses."[88]

To see the differences produced by these alternate approaches, consider again Skirbekk and Gilje's problematic sentence: "[T]he average temperature on the surface of the earth when the human race is extinct will be 70EC."[89] It will be impossible to test this assertion by experiment after all of the possible experimenters are gone. Popper's definition of science therefore marks this statement as unscientific, however dubious this conclusion may seem.[90] The more tolerant verificationist approach, however, allows for the drawing of inferences as a means of scientific inquiry.[91] Thus, we can attempt to verify the "70EC" statement by subtracting an estimate of human contributions from existing temperatures, by consulting prehistoric averages, or by undertaking any number of other calculations that will provide arguments for or against the statement. Verificationists might find any given result of these calculations either persuasive or unpersuasive, but they would not reject such methods as unscientific merely because the statement cannot be falsified.[92]

The verificationist approach also implies that science can include proof by negative inference, which is sometimes called proof by elimination or reductio ad absurdum.[93] Logicians ranging from the ancient Greeks to Sherlock Holmes have used this method, but the classic example is Euclid's proof that the catalogue of prime numbers is infinite, which he composed by showing that the opposite conclusion is erroneous.[94] In fact, there are other

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87. *See* CARL G. HEMPEL, *Studies in the Logic of Confirmation*, *in* ASPECTS OF SCIENTIFIC EXPLANATION AND OTHER ESSAYS IN THE PHILOSOPHY OF SCIENCE 3, 3–46 (1965); CARL. G. HEMPEL, *Empiricist Criteria of Cognitive Significance: Problems and Changes*, *in supra*, at 101, 101–20.

88. *See* HEMPEL, *Studies in the Logic of Confirmation*, *supra* note 87, at 43–45.

89. *See supra* note 76 and accompanying text.

90. *See supra* note 83 and accompanying text.

91. *See supra* notes 84–86 and accompanying text.

92. *See supra* notes 84–86 and accompanying text.

93. "[O]ne assumes a claim for the sake of argument, derives an absurd or ridiculous outcome, and then concludes that the original assumption must have been wrong as it led to an absurd result." *See* Wikipedia, Reductio ad Absurdum, http://en.wikipedia.org/wiki/Reductio_ad_absurdum (last visited Sept. 28, 2008). Reductio ad absurdum is also called the "apagological argument," "proof by contradiction," or "proof by the law of excluded middle." *Id.*

94. *See id.* Euclid's proof is as follows: suppose there are only finitely many primes. Compile the complete list, p_1 to p_n. Then, find the number $P = (p_1 \times p_2 \times \ldots p_n) + 1$. Now, this P cannot be a multiple of any of the "little p's" because division will leave a remainder of 1. Therefore, P must be a prime. In conclusion, the original supposition is eliminated as false, and there must be infinitely many primes. *See id.*

important scientific techniques that depend upon proof by elimination. For example, the Federal Judicial Center's Reference Manual on Scientific Evidence suggests that disease causation is determinable through a "differential diagnosis," from which the pathologist "considers all relevant potential causes of the symptoms and then eliminates alternative causes based on a physical examination, clinical tests, and a thorough case history."[95] Thus, a differential diagnosis does not attempt to falsify the resulting diagnosis by experiment; rather, it uses proof by elimination. Still, any disciple of Popper who deduces that the differential diagnosis method is "unscientific" is in the position of disparaging a thinking pattern that many scientists find valuable.

Inferences from irreducible complexity provide another example of proof by elimination. In effect, the proponent begins by saying the following: "Suppose for argument's sake that the bacterial flagellum evolved through natural selection." The irreducible complexity proponent then attempts to demonstrate that this conclusion is absurd by examining the complexity of the mechanism, showing the interdependence of its parts, and then comparing the result to the paradigm of natural selection. I find this argument difficult to accept, but I would resist the conclusion that the underlying method of reasoning by elimination is unscientific, even if it means that the conclusion is not falsifiable by an experiment congenial to Popper. This is especially so when there is no consensus about any pathway for creating the flagellum by natural selection, much less a clear method of testing or falsifying such a pathway. Thus, whether the irreducible complexity conjecture is scientific depends in part upon whether one rigorously follows Popper in every case—which I think is hard to do[96]—or whether one accepts the broader methods of the verificationists at least some of the time. Arguments against irreducible complexity and intelligent design often fail to recognize the difference between falsificationist and verificationist approaches to science, and they tend not to credit proof by elimination under either theory.[97] This is a flaw in the argument of those who oppose the teaching of irreducible complexity.

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95. FEDERAL JUDICIAL CENTER, REFERENCE MANUAL ON SCIENTIFIC EVIDENCE 214 (1994).

96. Insisting upon falsification arguably makes nonscientists out of many scholars who seem to deserve the label, from paleontologists to biological taxonomists. *See infra* Part II.B.

97. In *McLean v. Arkansas Board of Education*, 529 F. Supp. 1255, 1267 (E.D. Ark. 1982), the court stated that, "[t]he essential characteristics of science are: (1) It is guided by natural law; (2) It has to be explanatory by reference to natural law; (3) It is testable against the empirical world; (4) Its conclusions are tentative . . . ; and (5) It is falsifiable." This definition obscures the difference between verificationists (who seem to be included in the third criterion, "It is testable against the

3. William James and the Pragmatists: Testing Science by "What Works"

Still others adopt a pragmatic definition of science. William James, for example, considered that a scientific statement came to represent truth if it proved its utility for solving concrete problems over the long term.[98] The opposite was not exactly falsification but a failure of workability, by which a proposition ceased to provide a helpful option.[99] F.C.S. Schiller developed the idea that scientific truth was relative to specific problems.[100] If someone wants to return home, for example, the "true" answer will be whatever works to help that person to achieve that purpose.[101] To quote a more modern and entertaining source, namely, Professor Robert Adair in *The Physics of Baseball*: "In his analysis of a real system, a physicist constructs a well-defined model of the system and addresses the model."[102]

Thus, an equation, principle, or model is scientific only in context and only to the extent it has pragmatic value in helping an individual to solve an identifiable problem. The phenomenon that we know as light, for example, may be treated by particle theory (light is particles, like infinitesimal baseballs) or wave theory (light is waves).[103] Particle theory is useful in addressing certain issues such as the photoelectric effect, whereas wave theory is more useful in explaining phenomena such as color or

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empirical world") and falsificationists (who insist, as in the fifth criterion, that science must be "falsifiable"). *See also* Kitzmiller v. Dover Area Sch. Dist., 404 F. Supp. 2d 707, 735 (M.D. Pa. 2005) (referring to "testable, natural explanations" or those "inferred from the confirmable data," such as verificationists might accept, without distinguishing the falsificationist approach). As for proof by elimination, the *Kitzmiller* court apparently considered it flatly illegitimate: "[Intelligent design] proponents primarily argue for design through negative arguments against evolution . . . . However, we believe that arguments against evolution are not arguments for design . . . just because scientists cannot explain today how biological systems evolved does not mean that they cannot, and will not, explain them tomorrow." *Id.* at 738. The *Kitzmiller* court's reasoning here is sophistry. First, irreducible complexity can have scientific value even if its opponents may someday propose possible answers to its criticisms because conjecture that leads to new insights is valuable even if the conjecture someday proves wrong. *See infra* notes 138–40 and accompanying text. Science is "tentative," after all. Second, the burden on proponents is not to obliterate the opposition conclusively in all respects and for all time; instead, at least under a verificationist approach, it is to construct their arguments by inferences from evidence, which may include proof by elimination.

98. WILLIAM JAMES, PRAGMATISM, A NEW NAME FOR SOME OLD WAYS OF THINKING: POPULAR LECTURES OF PHILOSOPHY 204–07 (1907).

99. *See id.*; *see also* Wikipedia, Pragmatism, http://en.wikipedia.org/wiki/Pragmatism (last visited Sept. 28, 2008).

100. Pragmatism, *supra* note 99.

101. *Id.*

102. ROBERT K. ADAIR, THE PHYSICS OF BASEBALL 1–2 (2d ed. 1994).

103. *See* ROLAND LANE REESE, UNIVERSITY PHYSICS 602–04, 1053–54, 1104–05, 1235–39 (Keith Dodson & Beth Wilbur eds., 2000).

interference.[104] In other respects, tiny baseballs and roiled oceans have only the faintest resemblance to light, and as constructs within the human mind they seem contradictory (how can light consist of little baseballs and, at the same time, consist of waves?), but the two models both are scientific to the extent that they are useful to solve the particular problems to which they are adapted.

My own statement elsewhere of a proposed test for evaluating scientific models, for example, expands traditional criteria of tractability, simplicity, and empirical verification into six factors: communicability, computational tractability, simplicity of elements, generality, empirical accuracy, and recognizability of the limits of the theory.[105] In this view, whether a statement is scientific depends on simultaneous evaluation of these six indicia, as well as the use to which we plan to put the theory.[106] The "meatball" vision of an atom, as composed of orbiting electrons, might be "scientific" if we are trying to explain the subject to fourth graders, but for more sophisticated purposes, it is inaccurate and falsified—and we might need something more complicated, such as Schrodinger's wave equation.[107]

Pragmatism might be called the "American" model of science, as opposed to the British school represented by Popper. The American approach is to treat scientific theories as scientific if they "work"—a distinctly American concern.[108]

B. The Trouble with Definitions of Science

Popper's theory has the merit of distinguishing science from some other bodies of belief or knowledge that should be regarded as unscientific.[109] For example, moral precepts such as the Golden Rule ("do unto others") are not testable. Likewise, prescientific myths, religious beliefs, and pure mathematics are not science. Furthermore, Popper helps us to realize that

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104. *Id.*

105. Crump, *The Trouble with* Daubert-Kumho, *supra* note 59, at 28–39.

106. *Id.*

107. *See* REESE, *supra* note 103, at 163 (describing the meatball version, also known as the "Bohr model"). Reese also provides a reasonably accessible explanation of the quantum mechanics model, although useful models require mathematics that would resemble a forest of squiggles to most people. *Id.* at 1260, 1263–64. An intermediate conception, the "plum pudding model," conceives of the electron as a charged mass or cloud. *Id.* at 763.

108. *Cf.* 25 ENCYCLOPEDIA BRITANNICA 667–76, 678–92 (1989) (including the observation that although Popper was Austrian, his falsification criterion is identified with the British view, whereas the American view has emphasized "what works").

109. *See* Haack, *supra* note 83 and accompanying text (introducing the concept of "demarcation").

new data can change the result of testing.[110] If we were to examine American attitudes toward school desegregation in the 1950s, 1960s, 1970s, and 2000s, for example, we might draw theories about what the empirical results mean that would change with time, and Popper would have alerted us to watch for this.

But the trouble is that Popper's criterion might logically wind up labeling as "pseudoscientific" a number of disciplines that we might think deserve the label of science. For example, we cannot test the hypotheses made by paleontologists. Their conjecture that dinosaurs may be the ancestors of birds, for instance, can be corroborated by numerous kinds of observations and by induction and deduction from them,[111] but we cannot experiment very well with paleontology. Specifically, we cannot test the idea that dinosaurs produced birds, nor can we figure an observational manner of falsifying the hypothesis if it happens not to be true. If we address the question by the method of the verificationists, however, we come to the opposite conclusion. The paleontologist uses evidence, together with induction and analogy, to conclude from successive fossils that the progression from dinosaurs to birds is likely to have occurred. For the verificationist, who sees less demarcation between science and other types of reasoning, this is enough. But if we apply a strict and exclusive test of falsifiability, the paleontologist is not a scientist.[112]

Furthermore, Popper's definition makes a non-scientist out of anyone whose work consists more of rationalist correlation of data than of observation. For example, the falsificationist approach forces us to conclude that a biological taxonomist, who infers relationships among species and classifies them by similar characteristics, is not a scientist. The assignment of organisms to phyla and species, which are definitional constructs, cannot be tested by experiment. Thus, the statement that a whale is a mammal must be unscientific, if we strictly apply Popper's philosophy.[113] A whale resembles other mammals in some respects, it is true; but there are also ways in which it differs from, say, a horse, which the taxonomist tells us is also a mammal. It might be equally supportable by observation to create a classificatory system by which a whale is treated as a fish.[114] The existing

110. *See supra* notes 79–81 (discussing the absence of confirmation).

111. This corroboration has created an "almost universal consensus." *See* Wikipedia, Dinosaur, http://en.wikipedia.org/wiki/Dinosaur (last visited Sept. 28, 2008).

112. The qualifier, "a strict and exclusive" test of falsifiability, is important here. Popper's views actually changed from time to time, and he sometimes applied his falsifiability test in varying ways. *See infra* note 120 and accompanying text (containing a striking example). The point here, however, is that without respect to the conclusions Popper reached about whether certain specific disciplines were or were not "scientific," we eliminate many kinds of putative scientists if we faithfully apply his falsifiability test according to its terms.

113. *See supra* note 112.

114. For example, if we describe a "fish" as a vertebrate that lives exclusively in an aquatic

classificatory system might appeal to a pragmatist, who would see it as useful in generating hypotheses, and it might also appeal to an inductivist or verificationist who accepts evidence of various kinds in support of inferences, not just experimental observation. But the falsificationist theory is narrow-minded, and it shuts out the biological taxonomist if it is applied exclusively according to its terms.

Moreover, Popper excludes learned men and women who have contributed mightily to the growths of their disciplines as sciences. Consider Sigmund Freud, for example, whom Popper specifically intended to exclude.[115] Freud's theories of the subconscious were based upon observation, although they were not systematically recorded or controlled.[116] The rationalist elements of Freud's proposal of the "dream censor," for example, along with other aspects of his theory of dreams, were based upon Freud's years of listening to patients' free associations, but they reflected Freud's intellectual constructs even more.[117] Today, many psychologists have no use for Freud, although some of his theories have come to be accepted through observation or experiment.[118] The trouble with denying him a place in science, however, is that the methods that he used, the questions that he asked, and the hypotheses that he generated have led to the development of theories that unquestionably allow prediction—and therefore testing. Popper's views do not leave room for the critic who questions or the great thinker who surpasses his time.

Thus, almost any effort at demarcating science will raise the question, "If it advances science, isn't it worthy of being called science (or at least, being considered valuable to science), even if it doesn't rigorously fit someone's definition of 'science'?" Isn't a good question—a suggestion for fruitful inquiry—a part of science, even if it isn't falsifiable (or even verifiable)? Isn't the theorist (even the radical theorist, like Galileo or Darwin) who ultimately turns out to be wrong[119] still a "scientist" if the theory produces other theories that are "scientific"?

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environment and uses fins or a tail for locomotion, then a whale becomes a "fish." The definition might even have some slight appeal to pragmatists because we could predict certain similarities among species of "fish" defined this way (e.g., in skin characteristics). The real point, however, is that neither classification of a whale—as a mammal, or as a fish—can be falsified.

115. *See* POPPER, *supra* note 66, at 33–69.

116. *See* CRUMP, *supra* note 33, at 351–54.

117. *See id.*

118. *Id.*

119. Galileo was spectacularly wrong sometimes. For example, he denied that the moon had anything to do with causing tides. *See* Galileo Galilei, *supra* note 33.

C. *Science, Intelligent Design, and Natural Selection*

One might think that Popper would have an easy time in recognizing Darwinian natural selection as a scientific hypothesis. Strangely, one would be quite wrong. The natural selection question was a difficult one for Popper. Professor Susan Haack describes the twists and turns that Popper went through in considering this question:

> Indeed, Popper himself doesn't seem quite sure how to apply his criterion. Sometimes, for example, he says that the theory of evolution is not falsifiable, and, so, is not science; at one point, he suggests that "survival of the fittest" is a tautology, or "near-tautology," and elsewhere that evolution is really a historical theory, or perhaps metaphysics. Then, he changes his mind: evolution is science, after all.[120]

At first blush, it seems sensible to conclude that Popper finally got it right with the last conclusion because instinct tells us that natural selection is subject to falsification. Through experiment with a controlled biota, one can demonstrate that a process of natural selection results, or so we might surmise. But then again, one can ask whether this experiment really would give us the potential for falsifying the theory if it were untrue. We can begin with a given biota and note its change over time, or we can control some aspects of the biota and see what happens. And then, we will have data that shows that the system changed because we began with one set of flora and fauna and ended with another. But in the end, we should ask whether this data really matters—whether we have tested the "survival of the fittest" in any meaningful way. We have shown that the biota changed, and that the fittest survived, but because we define those that survived as the fittest, have we really tested anything other than the metaphysics or the tautology that makes us surmise or guess that it is the "fittest" that have survived? If not, then Popper's earlier view was correct, and natural selection is a "near tautology." The "fittest" have survived because we label those that survived as the fittest.

But the real point is that, even if we can call this experiment with changing biota a chance for falsification, it is difficult to say that we can do so for all aspects of evolutionary biology that we might consider to be scientific. Paleontology, for example, remains elusive. It is difficult to test the idea that birds evolved from dinosaurs by means that could falsify the

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120. Haack, *supra* note 83, at S67 (citing KARL POPPER, *Natural Selection and Its Scientific Status*, *in* A POCKET POPPER 239, 239–46 (David Miller ed., 1983)).

theory, although we may be able to infer it from ample evidence.[121] We can study fossils and note that scales became more like feathers over time and appendages more like wings. But this is the method of inductivists or verificationists, not of the scientist who insists on falsifiability.[122] Similarly, the biological taxonomist is still a non-scientist, irrespective of the evidence that supports his hypotheses.[123] And then, there is the example of the bacterial flagellum. Biologists have proposed evolutionary pathways for the development of flagella, as I have observed in an earlier part of this article.[124] But then, how do we test these flagellum-development theories in a manner that will falsify them if they actually are untrue? Some scientists seem confident of discovering means for empirical testing of flagellum evolutionary theories.[125] The fact is, we simply do not know whether there are such means or not.

D. Does It Matter Whether Irreducible Complexity Is or Is Not Science If We Already Teach It in Teaching Natural Selection?

One point to be made before proceeding further is that whether irreducible complexity theory meets any particular definition of science is not the ultimate issue. Most disciplines taught in public schools are not sciences. History, mathematics, English literature, and foreign languages are worthy of learning, and yet they are not sciences. Instead, the legal issue is whether coverage of irreducible complexity or intelligent design in a biology class is an establishment of religion. This issue, in turn, depends upon which of the Supreme Court's several approaches to the Establishment Clause we choose to use, and how we happen to apply it.[126] The separate issue—whether it is wise to include the subject—is a political question, depending upon our evaluation of the utility of including it and the resources consumed in doing so, or the costs and benefits. Both questions may depend in part upon whatever secular purposes there may be for teaching intelligent design.[127]

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121. *See supra* note 111 and accompanying text.

122. *See supra* notes 84–86 and accompanying text.

123. *See supra* note 112 and accompanying text.

124. *See supra* notes 7, 29 and accompanying text.

125. *See, e.g.*, Musgrave, *supra* note 7 (proposing means of testing); *see also supra* notes 29–30 and accompanying text (explaining Musgrave's and Matzke's proposed pathways).

126. *See infra* Part IV (discussing the Establishment Clause).

127. *See infra* Part III (discussing the secular purposes derived from teaching intelligent design).

And it should immediately be added that we already teach irreducible complexity and intelligent design in teaching natural selection. Paradoxically, it is necessary to raise the theory of intelligent design in biology classes and definitively to reject it if we are to teach evolution; it is virtually impossible to do otherwise.[128] The teaching is usually done in dogmatic fashion, consisting of firm, unquestioning denunciation of intelligent design as erroneous. Specifically, understanding natural selection requires clear absorption of the principle that natural selection depends upon random events. It is non-purposive. For neophytes to comprehend natural selection, they must first eradicate the notion, however universally intuitive it may be, that the origin of species has any design behind it whatsoever.[129]

In fact, reasoning about natural selection requires students to make a serious effort at wringing every dollop of purpose out of their scientific statements. The observation that "the leopard grew its spots so that it could develop better camouflage," for example, is inconsistent with natural selection. Instead, the evolutionist's mode of thinking would sound something like, "Individual pre-leopard organisms happened by chance to produce spots (or precursors of spots), and these individuals procreated in greater numbers so that their offspring were naturally selected in their biota to become today's leopards."[130] Similarly, it is bad reasoning to assert that "giraffes grew long necks so that they could reach leaves on higher branches." The evolutionist's mode of thinking might instead propose that "precursors of giraffes survived and propagated at higher rates when their necks were longer, which happened as a result of random mutations."

Statements attributing purposeful development in species are properly called "teleological" statements. Teleology is an umbrella word referring to modes of thinking that explain phenomena by reference to unifying purposes, rational development, or, for that matter, intelligent design.[131] An instructor simply must eliminate teleological thinking of these kinds if the instructor is to teach natural selection meaningfully. Thus, the teacher must act to countermand statements such as "the leopard grew his spots for camouflage" or "the giraffe's long neck developed so it could reach higher

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128. This is so because "[p]opular reasoning about 'evolution' . . . is subject to a variety of errors, of which probably the most prevalent is inferring *purpose* in mutation." CRUMP, *supra* note 33, at 281 (emphasis added). In other words, the easy (but erroneous) inference is that since organisms sometimes can improve their Darwinian selection through adaptation, they must be exercising some unseen faculty to adapt, all *for the purpose of* surviving. Individuals do indeed exercise various faculties to survive. The error, however, consists in attributing this survival purpose to the entire species, as a species, or even in attributing the purpose to their biota as a whole.

129. *Cf. id.* at 281 (giving examples such as those in the next paragraph of the text as illustrations of erroneous applications of the theory, and explaining why they are "fallacious," as a means of teaching the random nature of natural selection). *See also infra* note 135 and accompanying text.

130. *See supra* notes 13–15 and accompanying text.

131. *See* CRUMP, *supra* note 33, at 209–10, 281.

vegetation." Teleological thinking, specifically the kind of teleological thinking inspired by irreducible complexity theory and referred to as intelligent design, must be eliminated root and branch. Thus, we already teach about intelligent design whenever we teach evolution. In other words, we set it up as a straw man, and then we inculcate the doctrine that it is wrong.

The raising and rejecting of intelligent design is such a necessary part of teaching natural selection that the subject usually is mentioned and disapproved uncritically, as an idea that simply must be discarded as a matter of the teacher's mere assertion.[132] Consider the following recommended means of denouncing any inference of purpose in the origin of species, quoted from a major high school biology book: "Address Misconceptions . . . . Give students the following example, which is typical of what they might read in a textbook: 'The bird evolved a larger beak.' This sounds as though an individual bird has intentionally changed its biological traits. Ask: What would be a more accurate way of stating this?"[133] The desired answer must be something like the following: "Mutations produced a larger beak in some individual birds and led to greater survival and propagation of those birds." Thus, the teacher's guide to this high school text encourages the raising of a purposeful or intentional force (an intelligent design), followed by the dogmatic rejection of the entire notion as a "misconception." Other teaching books contain similar dogmatic presentations. For example, one book pronounces that "evolutionary change occurs without any 'goals.'"[134] "The idea that evolution is not directed toward a final goal has been . . . difficult for people to accept . . . ."[135] Again, I recognize that the teaching of evolution requires the teacher to make this point, and I concur with that approach. However, I object to the pretense that the teacher is not teaching intelligent design, because she is. She also is teaching that it should be rejected dogmatically without any reasoning whatsoever.

I do not wish to be misunderstood, and therefore I repeat: I believe that natural selection is overwhelmingly supported by the evidence. It should be taught as a view of reality that explains vast reaches of phenomena consistently with observation. And when it is taught, the necessity of

132. *See supra* note 128 and accompanying text.

133. KENNETH R. MILLER & JOSEPH LEVINE, TEACHER'S EDITION BIOLOGY 376 (Tex. ed. 2004). This book is published by Prentice Hall, a well-known publisher of high school texts.

134. PURVES ET AL., *supra* note 13, at 3.

135. *Id.*

avoiding any vestige of teleological thinking should also be taught. My contrarian view is not based upon any rejection of natural selection or of its inconsistency with teleology. Again, what I object to is the pretense that biology courses do not already cover intelligent design by uncritically denouncing it when they teach natural selection. I also think that there are many sound reasons for considering irreducible complexity as a separate theory, with slightly more suspension of disbelief than those who would exclude it from the public square are willing to indulge in today, and this is the subject of the next section of this article.

III. WHAT IS TO BE GAINED BY STUDYING IRREDUCIBLE COMPLEXITY?: A CATALOGUE OF SECULAR PURPOSES

The previous part of this article has discussed science and its varying definitions.[136] This part will build upon that discussion by identifying a number of secular purposes that can be served by the teaching of irreducible complexity. Cataloging and explaining those purposes is useful not only for its own sake—to evaluate whether the study of irreducible complexity is worthwhile as a matter of policy—but also to consider whether it results in an unconstitutional establishment of religion if done in public schools. The constitutional question will be addressed in a later section, after the secular purposes are considered.[137]

A. Better Understanding of the Nature of Science

The history of science is littered with the wreckage of theories that failed. The Ptolemaic universe, for example, proposed an earth-centered universe orbited by the sun and planets.[138] Politically correct astronomers of an earlier time even dreamed up epicyclic planetary movements to conform the theory to observations of "regression," when planets seemed to backtrack in the sky.[139] The Copernican universe, which in its early forms appears to have treated orbits as circular, improved on the Ptolemaic universe by having the earth circumnavigate the sun, and later recognition of elliptical orbits improved the theory still.[140] As imperfect as the Ptolemaic universe may have been, however, it was an improvement over conceptions of the sun as powered by a deity driving a fiery chariot. But then, even pre-scientific

136. *See supra* Part II.
137. *See infra* Part V.
138. *See* CRUMP, *supra* note 33, at 309–10.
139. *Id.*
140. *Id.*

creation myths of that kind have been recognized as the beginnings of modern cosmology.[141] Such is the nature of science.

Biology has seen similar false developments as counterparts to natural selection. Lamarckian evolution, for example, proposed the inheritance of acquired characteristics.[142] If the life experience of a particular organism caused it to acquire strength, or markings, or higher intelligence, Lamarckians believed that its offspring would inherit those characteristics.[143] This theory is discredited by observation; it has been falsified.[144] Other discarded alternatives have explained the development of species by spontaneous generation, or in other words by creation of conditions hospitable to particular organisms in the manner of food scraps "generating" rats or humid wood "generating" mold.[145] Still another theory has explained the origin of species by suggesting that developed life forms were introduced into the biosphere by celestial bodies falling to earth.[146]

It may be useful to introduce discredited ideas of this kind at the beginning stages of teaching evolution so that the student can examine the evidence that falsifies them. These alternative theories mirror ideas that people are accustomed to accepting, even if they are founded on unscientific concepts. Thus, the teaching of evolution may prove more successful if it includes a segment that contrasts natural selection with discredited, but easily accepted, theories. The fundamental nature of evolution as a phenomenon founded on random processes may be better understood this way. In fact, courts have recognized a possible value in teaching theories that have failed—and showing why.[147]

None of these alternative ideas provides a counterpoint to evolutionary science nearly so well, however, as irreducible complexity. The inference for this counter-hypothesis is supportable by various kinds of evidence, ranging from the nature of the earth as hospitable to life, to the hierarchy of species, and to the design of the solar system. It is too easy to falsify

141. *See* Wilson, *supra* note 31, at 33 ("Creation myths were in a sense the beginning of science itself.").

142. CRUMP, *supra* note 33, at 281–82.

143. *Id.*

144. *Id.*

145. *Id.*

146. *See* McLean v. Ark. Bd. of Educ., 529 F. Supp. 1255, 1269 (E.D. Ark. 1982) (proposing that, as a foil to evolution and as an example of a false theory, public schools use a theory based on comets striking earth and depositing pre-life-form material, instead of purposive (teleological) theories).

147. *Id.*

Lamarckian evolution or spontaneous generation.[148] It also is possible to falsify irreducible complexity, at least in many, if not most, applications.[149] However, irreducible complexity is more stubborn, and it is impossible to demonstrate or test evolution by natural selection as an explanation for some phenomena as of yet.[150] For this reason, irreducible complexity makes a better foil to natural selection. In fact, the naturalness of the inference of irreducible complexity furnishes a reason why intelligent design is usually taught (or taught about)—as a theory to be denounced without analysis—whenever evolution is taught.[151]

Furthermore, investigation of the history of science is often viewed as integral to the understanding of science. For example, many psychologists today may have no use for Freud and may not regard his theories as scientific, but a survey course about psychology would sensibly include examination of Freud's work as a means of understanding how the field of psychology has developed.[152] Besides, some of Freud's theories have been corroborated by later experimentation, even though many Freudian theories either have not survived observation or cannot be falsified or corroborated.[153]

In summary, one would understand natural selection more completely by considering counterparts that may be false, true, or only true some of the time. Thus, teaching about Lamarckian evolution as a false theory helps students to understand evolution by natural selection. Teaching about irreducible complexity as a theory that does not explain many kinds of observations but conceivably (perhaps barely conceivably) may explain a few—and that cannot yet be falsified in those areas, although possibly it will be someday—may provide an even better way of enhancing understanding of natural selection.

B. Stimulation of New Scientific Inquiries

Criticism of new or established theories is a part of science. The development of the Copernican universe, for example, was spurred by observations of planetary movement that seemed to disprove established thought.[154] Astronomers proposed that planets traveled in epicycles to solve

148. *See supra* notes 79–81 and accompanying text.

149. *See supra* notes 29–30 and accompanying text (proposing evolutionary pathways for the development of the bacterial flagellum and means of testing them—means that potentially would falsify the irreducible complexity conjecture).

150. *See supra* notes 29–30 and accompanying text (discussing testing methods that have been proposed).

151. *See supra* Part II.D.

152. *See supra* notes 115–18 and accompanying text.

153. *See supra* notes 115–18 and accompanying text.

154. *See supra* notes 138–40 and accompanying text.

this problem.[155] The planets stubbornly failed, however, to conform to these theories.[156] The focus that is brought to a problem by criticism and proposed solutions supports the development of science even if the proffered theory turns out to be wrong.[157]

Theories that are precursors of irreducible complexity have, in fact, spurred the development of evolutionary science. Critics of natural selection pointed to the absence of what they called "transitional forms" in the fossil record.[158] A simplistic view of evolution might view it as a smooth process of "evolutionary" change, in which transitions from a remote ancestor go through identifiable intermediate stages. The trouble with this idea was that fossils in some instances showed what appeared instead to reflect sharp changes, and critics argued that this evidence undermined the theory of evolution.[159] In response, biologists developed a theory of "punctuated equilibrium."[160] In time, a biota reaches a relatively stable phase in which organisms do not evolve rapidly because although there are random mutations, nothing in nature causes them to be naturally selected.[161] But then, a catastrophe changes the playing field. It may come in the form of planetary temperature increases, an ice age, or the collision of two tectonic plates that creates a land bridge introducing new predators.[162] In this situation, the change brought about by natural selection begins suddenly, proceeds rapidly, and involves large sectors of the biota. Evolution is a misleading term unless one understands that it can proceed with dramatic leaps in short time frames and that long periods of relative equilibrium can be punctuated by moments of rapid change. This insight was encouraged by the opponents of natural selection.[163] In other words, the creationists' criticisms may have been wrong in the minds of most scientists, but our understanding of evolution improved because of questions such as the ones they raised.

Irreducible complexity theory has already performed a similar function in stimulating scientific advances. The evolution of systems with many elements, those that advocates of intelligent design argue are irreducibly

155. *See supra* notes 138–40 and accompanying text.
156. *See supra* notes 138–40 and accompanying text.
157. *See* CRUMP, *supra* note 33, at 282.
158. *Id.*
159. *Id.*
160. *Id.*
161. *Id.* at 282–83.
162. *Id.*
163. *Id.*

complex, are the subject of intense inquiry today. The current effort to explain the emergence of the bacterial flagellum may lead to new thinking about natural selection itself, and evolutionary pathways for other complex functions already have been proposed as a result of the irreducible complexity critique.[164] "Exadaptation," or the development of a complex organ by reason of a change in function from mutations to a simpler organ, is one pathway that natural selection biologists have proposed in response to intelligent design theory.[165] Furthermore, means of testing these new theories are also the subject of inquiry. It seems likely that these efforts will generate not only new theories to address the criticisms of irreducible complexity advocates but also new means of subjecting new theories of evolution to experimentation.[166]

C. Better Examination of the Question—"What Is Science?"

Intelligent design involves a negative inference. It depends upon the assertion that natural selection cannot explain phenomena exhibiting what advocates call irreducible complexity. Thus, intelligent design is based on reasoning that, if evolution through chance mutations is eliminated, an intelligent design must have produced these phenomena. A definition of science that depends exclusively upon falsification, such as Popper's approach, might deem the second step—the inference of intelligent design—unscientific.[167] At the same time, it should be remembered that a strict falsificationist approach to demarcation of science also eliminates paleontology from the ranks of sciences.[168]

A different view, one that allowed science to depend upon inferences from evidence rather than falsification by experiment, would reinstate paleontology as a science. At the same time, such a verificationist approach might recognize irreducible complexity as a scientific hypothesis because advocates of irreducible complexity base their arguments upon evidence and inferences from them.[169] Proof by negative inference, or reductio ad absurdum, has been recognized since ancient times as a valid method of deduction (although it remains debatable whether the method can correctly

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164. *See supra* notes 7, 29–30 and accompanying text.

165. "Exadaptation" refers to a change in function of an existing organ: a change by which an organ furnishing excretory outlets, for example, also furnishes crude locomotion that is improved upon by further adaptation until the organ has become an instrument for locomotion rather than excretion. It also is called "cooptation." *See supra* notes 7, 29 and accompanying text. Actually, Darwin himself proposed the idea of the "transitions of organs" by "conversion from one function to another." DARWIN, *supra* note 19, at 160.

166. *See supra* notes 29–30 and accompanying text.

167. *See supra* Part II.A.1.

168. *See supra* note 112 and accompanying text.

169. *See supra* Part II.A.2 (discussing the verificationists' approach).

be used here).[170] Thus, while the rigorous falsificationist probably would deny that irreducible complexity, along with paleontology, is scientific, a more expanded definition of science might treat it as scientific. Studying both theories (natural selection and irreducible complexity) may advance understanding of the nature of science.

In fact, irreducible complexity and its corollary of purposeful design provide an interesting example for considering different conceptions of science. With different answers to the question—"What is science?"—one can produce different answers to the question whether the irreducible complexity critique of evolution is scientific. In other words, the falsificationist, verificationist, and pragmatist views give us different outcomes.

First, if the rigid falsification criterion is the exclusive method of demarcating science from other kinds of logic, then it probably will force us to label irreducible complexity as unscientific because it cannot be tested by experiment. The closest we can come is to propose evolutionary pathways for given organisms or systems and then attempt to falsify those pathways. For example, we can propose that a particular bacterial flagellum developed by exadaptation from a secretory organ, and we can attempt to "grow" a similar flagellum in the laboratory by reproducing the conditions that we imagine might have stimulated this exadaptation.[171] If we are able to do so, we might conclude that irreducible complexity theory is falsified. If we are unable to do so, it is not falsified—or so we might reason.

But there are serious problems with using this approach to test irreducible complexity. First, we probably will not have simulated the random means by which the particular flagellum developed, especially if we create conditions that we already think will lead to precisely that development. Second, there are many bacterial flagella and infinitely many potential complex systems in all of the organisms on earth, and the discovery of one or more pathways for one or more complex systems cannot falsify the hypothesis that some of them may reflect complexity that is irreducible. Third, our ability to grow a flagellum that resembles a particular natural flagellum does not falsify the possibility that the natural flagellum is irreducibly complex. It seems difficult, then, to conclude that either irreducible complexity or intelligent design is falsifiable.

Second, there is the verificationist or inductionist approach. Here, our criteria expand beyond falsification. We still insist that proponents of the

170. *See supra* notes 93–94 and accompanying text (discussing reductio ad absurdum).

171. *See supra* notes 7, 29–30 and accompanying text.

irreducible complexity argument base their ideas on appropriate evidence and use cognizable logic in reaching their conclusions, but falsifiability is not the only qualifier. Under this definition of science, evolutionary theorists who propose pathways for development of the bacterial flagellum are scientists by reason of the kinds of inferences they make, irrespective of whether their ideas are testable.

But what about irreducible complexity? Here is how the difference in definition makes a difference in result. Arguably, the irreducible complexity theorist—such as Michael Behe, the leading proponent of the flagellum example[172]—is no less a scientist than the straight evolutionary theorist under the verificationist criterion. This individual also uses evidence and logic. Behe's principal argument—that the flagellum fits into "Darwin's Black Box" because of its complexity—uses evidence and inference in much the same way as the paleontologist's theories do.[173] It also relies on proof by elimination, or the inference that evolutionary development of such a complex mechanism is improbable. Although the evolutionist's theories do not depend on this kind of negative inference, reductio ad absurdum is a competent logical argument.[174]

As it happens, Behe's application of the logic is ultimately unconvincing to me and to others because his reductio ad absurdum argument does not take adequate account of exadaptation: the possibility that the combination of disparate parts came together after a series of changes in function of pre-existing organs, rather than appearing simultaneously.[175] Behe has acknowledged the flaw, and at least one court has rejected Behe's claims as unscientific on this ground.[176] This result seems a trifle harsh because we cannot defrock every scientist who makes a miscalculation.[177] If science is defined by a broad verificationist or inductivist methodology, then Behe's development of the irreducible complexity hypothesis is science. It may not be persuasive in light of the possibility of exadaptation, but that alone does not make it unscientific.

Third, there is the view of the pragmatists. Their test of scientific truth depends upon whether the theory helps an individual to solve a given problem or form the basis of a decision to act.[178] Irreducible complexity and intelligent design seem to fail this test. Knowing that an organism is the product of "design" and is "irreducibly complex" does not seem to help us

172. *See supra* notes 7, 29–30 and accompanying text.

173. *See* BEHE, *supra* note 18 and accompanying text.

174. *See supra* notes 93–94 and accompanying text.

175. *See supra* note 165.

176. Kitzmiller v. Dover Area Sch. Dist., 400 F. Supp. 2d 707, 739 (M.D. Pa. 2005).

177. *Cf. supra* note 119 (describing a major error made by Galileo, despite his many scientific achievements).

178. *See supra* Part II.A.3.

solve a problem or decide how to act with respect to the organism. In other words, these conceptions probably cannot tell us at the theoretical level how to predict this or that development, and they cannot point the way toward preventing disease or enhancing the utility of foodstuffs at the concrete level.

Understanding Darwinian evolution, on the other hand, does help solve problems and indicate action. At the theoretical level, natural selection theory tells us that bacteria will evolve forever. At the concrete level, it tells us that we had better keep developing new antibiotics to kill bacteria that adapt to the old ones.[179] This analysis suggests that the pragmatists' approach would indicate that evolution is a scientific construct—but that irreducible complexity and intelligent design are not.

The point, however, is that this conclusion depends on which definition of science we use in analyzing these theories. The pragmatist and falsificationist might see irreducible complexity as unscientific, but the verificationist might not. The further point is that defining science narrowly brings about results that seem questionable. Finally, studying irreducible complexity arguments provides an excellent vehicle for studying different answers to the question—"What is science?" This, too, is a positive secular purpose.

D. Generating the Ability to Argue Against Intelligent Design

Most efforts to teach natural selection include a rigorous effort to eliminate teleological explanations. This effort is necessary because teleological impressions are strong in many people and prevent an understanding of the mechanism of natural selection unless they are dispelled at the beginning.[180] But a dogmatic rejection of teleological explanations, while inconsistent with acceptance of irreducible complexity theory, will not help a student very much in deciding whether to accept or reject intelligent design. It will serve even less to equip a student to argue against the conclusions of an informed advocate of irreducible complexity. For that, one needs to understand the arguments in favor of irreducible complexity, as well as the contrary arguments of those who reject the theory.

Thus, one of the reasons that I advocate examination of irreducible complexity, although I myself consider natural selection overwhelmingly to

179. *Cf.* CRUMP, *supra* note 33, at 283 (discussing the emergence of vancomycin-resistant pathogens).

180. *See supra* notes 128–32 and accompanying text.

be the more likely valid approach, involves an apparent paradox. I think it is useful for students to study the arguments allegedly supporting irreducible complexity so that they can understand the arguments that refute irreducible complexity. In other words, they will have a basis for rejecting irreducible complexity if they so decide.

E. Understanding What the Majority of the Population Believes, as a Basis for Communicating and Negotiating With Others

The majority of American people believe that evolution is an erroneous theory.[181] The statement seems astounding, but at least one poll clearly supports it.[182] This does not mean that all who reject evolution credit irreducible complexity or even understand it, but there must be many in the population who harbor teleological beliefs about the origin of species.

Communicators who do not understand the belief systems of those to whom they aim their ideas are less likely to be successful. To put the matter another way, a skillful person writing an advertisement, picking a jury, negotiating with others, trying to analyze voters, or seeking to win an election needs to understand the assumptions and attitudes of the audience.[183] An understanding of irreducible complexity would provide a sound comparison for the educated person of his or her own beliefs with the incompatible beliefs of others.

In some endeavors, in fact, it is necessary to bracket one's own thoughts and listen to the incompatible thoughts of others with whom one clearly disagrees. Negotiation and active listening are such endeavors.[184] The blithe condemnation of the teleological as wrong and the assertion of absolute rightness in doing so, which often accompany the teaching of evolution, send a dysfunctional message about these issues. Although it is not one of the more important purposes for teaching irreducible complexity, this concern for communicational abilities provides an additional, if lesser, reason. In other words, teaching irreducible complexity might produce not only better students of science but also better listeners and negotiators.

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181. Wilson, *supra* note 31, at 31. "[H]alf of Americans recently polled (2004) not only do not believe in evolution by natural selection but do not believe in evolution at all." *Id.*

182. *Id.*

183. *See* M. SCOTT PECK, THE ROAD LESS TRAVELED: A NEW PSYCHOLOGY OF LOVE, TRADITIONAL VALUES AND SPIRITUAL GROWTH 120–131 (1978) (explaining the difficulty and importance of "the work of attention," i.e., active listening).

184. *Cf.* CRUMP, *supra* note 33, at 520–23, 532–43 (discussing active listening and negotiation).

F. Understanding the Inconclusiveness of Scientific Theory

Scientists need to retain a detached skepticism about the permanence and universality of the theories that they accept. Surely Popper is right about at least this aspect of his thinking. Theories that seem to have been falsified may turn out later to require at least partial acceptance, and conclusions that seem overwhelmingly corroborated may turn out to require modification under different or special conditions, or even as general principles.

Thus Lamarckian evolution, in spite of its thorough falsification, has resurfaced in modern times as correct in at least one situation: genetic modification, which leads to propagation of acquired characteristics through the mechanism of altered genes.[185] Newtonian mechanics turn out to require modification under extreme relativistic conditions, such as those that are to be found in the vicinity of a black hole.[186] The cherished belief that the speed of light is a constant is challenged today by some cosmologists who propose a variable speed of light, which may have existed in the first instant of the expanding universe.[187] And during the writing of this article, an astronomy student discovered a massive supernova designated "SN2006gy," 240 million light-years away, that challenged basic scientific beliefs.[188] SN2006gy is not merely a supernova—its explosion was a hundred times bigger than any supernova seen before.[189] Older models would have suggested that SN2006gy was such a large star that it should have imploded to become a black hole, but that result does not appear to have occurred.[190] Actually, we do not know because what we see is what happened 240 million years ago. What we do know is that SN2006gy will require scientists to revise their theories about how stars live and die. "[T]his supernova shows pretty clearly that our knowledge is incomplete," said J. Craig Wheeler, an astronomer at the University of Texas.[191] Although there

185. *See* JOHNSON & RAVEN, *supra* note 13, at 228–29 (explaining genetic engineering).

186. *See* CRUMP, *supra* note 33, at 314.

187. *See* JOÃO MAGUEIJO, FASTER THAN THE SPEED OF LIGHT: THE STORY OF A SCIENTIFIC SPECULATION 156–59 (2003) (postulating a varying speed of light during the first instant of the universe, "in perfect contradiction to the fundamental principle underlying the conservation of energy," as a consequence of mathematical results and the need to explain creation of matter).

188. *See* Chris Wilson, *A Blast from the Past: A Huge Supernova Raises Questions About the Early Universe*, U.S. NEWS & WORLD REP., May 21, 2007, at 37.

189. *Id.*

190. *Id.*

191. *Id.*

should not have been any need for Professor Wheeler's understatement, the need is there, largely created by undue expectations of scientific knowledge.

Is it possible that we may learn of a place in biology for irreducible complexity theory? It seems doubtful to me, but I cannot rule it out. In fact, some thinking that favors intelligent design sees it as a kind of gap-filler. Advocates of this view accept the strong evidence that appears to support natural selection, but they argue that there are some phenomena that natural selection cannot explain. Specifically, they posit the existence of irreducible complexity, as it is illustrated by the bacterial flagellum.[192]

Others reject the idea, and while recognizing that we cannot confidently specify any particular mechanism for the emergence of the flagellum by natural selection, they predict that one day we will know the answer.[193] This thinking seems dangerous to me. It resembles the arguments of pseudoscientists who argued against the Copernican universe and who, in a triumph of irrational faith over science, made arguments that supported the censorship of Galileo's views.[194] In any event, encouraging a conscious decision to keep an open mind about the irreducible complexity critique would be consistent with most theories of the nature of science.

G. *Avoiding Censorship: "Teacher, What Do You Think Happened Before the Big Bang?"*

One of the costs of our attitudes toward irreducible complexity is that there is widespread censorship of legitimate inquiry as a result of it.[195] This is particularly so with respect to so-called "ultimate" questions. What happened before evolution even started? The question sometimes is put in terms of the "ultimate origins" of species, as versus their "proximate" origins. As Eugenie Scott puts it, "Although some people confuse the origin of life itself with evolution, the two are conceptually separate . . . . Life had to precede evolution! . . . [But w]e know much more about evolution than about the origin of life."[196] And there are other ultimate questions, including the one posed by the Dalai Lama: "Regardless of how persuasive the Darwinian account of the origins of life may be, as a Buddhist, I find it leaves one crucial area unexamined. This is the origin of sentience—the evolution of conscious beings who have the capacity to experience pain and pleasure."[197] When did thinking and feeling organisms evolve? But perhaps

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192. Michael Behe's views, for example, fit this description. *See supra* note 18 and accompanying text.

193. *See supra* note 31 and accompanying text.

194. *See supra* note 33 and accompanying text.

195. *See infra* notes 200–07 and accompanying text.

196. EUGENE SCOTT, EVOLUTION VS. CREATIONISM: AN INTRODUCTION 27 (2004).

197. THE DALAI LAMA, THE UNIVERSE IN A SINGLE ATOM: THE CONVERGENCE OF SCIENCE AND

the most inaccessible question of this kind involves the effort to account for the universe before the instant of its expansion in the Big Bang. The possibility of an oscillating or bouncing universe—one that expands from an infinitesimally small point to the enormous cosmos that we think of today, and then, possibly through the influence of gravity, compresses again to a point, only to explode again—is one theory.[198] But then, what started the oscillations?

These questions require at least an ingredient of speculation. Indeed, speculation is a part of the process of science. Students in public school biology courses may want to ask questions about these issues, but Establishment Clause concerns make it difficult to discuss possible answers. For example, a student may ask, "Teacher, what happened before the Big Bang, or if there is an oscillating universe, what put it into motion?" The result will probably be an awkward announcement that the question is out of bounds. Even more embarrassment arises, of course, if the student asks, "Where does God come into all of this?" The result is quite likely to include a suggestion that the very thought is impertinent. But imagine that the teacher dignifies the question by inviting discussion. Then, the controversy really begins.

The speculation that leads to possible answers to such a question may involve creation *ex nihilo* (out of nothing), creation out of chaos, or creation from a situation in which there was not even any "nothing" present. Each of these possibilities finds theological support in the creation myths of one or more of the major world religions.[199] The problem is that courts have held that consistency of answers with such myths—rightly or wrongly—is indicative of unconstitutionality.[200] A student may ask, "Why can't we make protoplasm that 'works' in the laboratory?" Almost any answer creates a similar danger. Even the Dover School District, which dared to introduce intelligent design into its curriculum, was fearful of letting students discuss these questions in school.[201] "The school leaves the discussion of the Origins of Life to individuals and their families," said its policy.[202] This is

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SPIRITUALITY 115 (2005).

198. *See* MAGUEIJO, *supra* note 187, at 106–07 (explaining the "bouncing" (or "oscillating") universe theory).

199. *See* GRIFFIN, *supra* note 1, at 563–67 (summarizing creation stories from various religions).

200. *See infra* Part IV.B (discussing the Supreme Court's decision in *Edwards v. Aguillard*, 482 U.S. 578 (1987), which considered similarities between a school board's policy and Judeo-Christian creation stories); *see also* GRIFFIN, *supra* note 1, at 585 (reproducing testimony relied upon by another court in similar ruling).

201. *See* Kitzmiller v. Dover Area Sch. Dist., 400 F. Supp. 2d 707, 709 (M.D. Pa. 2005).

202. *Id.*

unfortunate because scientific inquiry into origin-of-life questions might be valuable, and ruling the questions out-of-bounds in school is likely to discourage inquiry.

The result is a broader censorship—a banning of perfectly proper discussion. Why? Because constitutional law is not practiced with a scalpel. Instead, it is practiced with a chainsaw. It is broad, vague, and scary to a school district safeguarding public money, especially when backed up by expensive litigation that may be doubly expensive because attorney's fees are recoverable and may create crushing personal liability for individuals. It is difficult to handle a chainsaw legal principle in this environment so that it lops off only that which is unconstitutional without censoring protected speech. Although I do not know that the precise examples given above have created controversy, efforts to answer similar questions have led to litigation and therefore censorship.

Recently, a prospective high school teacher in California offered to teach an elective philosophy course—not a course on science or theology, but an elective course in philosophy, open to those who wanted it—called the "Philosophy of Intelligent Design."[203] Local parents sued, and the teacher changed the name to "The Philosophy of Design,"[204] apparently hoping that critics would appreciate the elimination of "Intelligent." Facing enormous attorney's fees claims as well as complaints, the school district ultimately cancelled the class.[205] The plaintiffs' attorney exulted, "This sends a strong signal to school districts across the country that they cannot promote . . . intelligent design, whether they do so in a science class or a humanities class."[206]

Well, yes, it does—but is that a good thing? The possibilities for similar kinds of "peripheral censorship," as it might be called, are infinite. For example, Leslie Griffin asks whether certain aspects of brain development or comparative religion can properly be taught anywhere in a public school and in such a censored environment:

> A public school teacher, following Darwin's ideas and relying on modern developments in neuroscience, added a section on neuroscience to her biology class. According to class readings, "the experience of God can be explained as nothing more than the effect of a particular state of brain organization" and the "Golden

203. *See* Laurie Goodstein, *California Parents File Suit Over Origins of Life Course*, N.Y. TIMES, Jan. 11, 2006, at A18.

204. *Id.*

205. *See School District Pulls ID Course After Suit*, CHRISTIAN CENTURY, Feb. 7, 2006, at 14, *cited in* GRIFFIN, *supra* note 1, at 617–18.

206. *See* Juliana Barbassa, *School Board Drops Philosophy Class in Intelligent Design*, HOUSTON CHRON., Jan, 18, 2006, at A5.

> Rule . . . is a product not of divine decree but of evolved instinct." The students learn that religious sensations arise from the areas of the brain that are specialized for religious emotion and thought. Does the teacher violate the free exercise rights of her religious students [or, for that matter, does she create an establishment of (anti-)religion] by teaching the neuroscience segment of the course? May the teacher include in the course readings from neurotheology, a discipline that claims that "the human brain itself is revelatory of information about God," because God hardwired our brains to seek meaning? May the state legislature require the teacher to teach neurotheology in her course?
>
> Some writers argue that religions themselves undergo an evolutionary process of "supernatural selection": "The religious movements that have survived over the years tend to be the ones that promote health, mate selection, and security." Where would you teach that thesis—in a science course, a religious studies course, a theology course, an economics of religion course, or not at all?"[207]

The plaintiff's attorney in the "Philosophy of Design" case has helped create an environment in which the answer is, "not at all." This kind of censorship is fundamentally inconsistent with the inquisitive speculation that is an essential part of both science and the humanities.

H. Teaching Epistemology Through Debate Among Inconsistent Theories That Cannot be Readily Reconciled

There are great questions that serve well to provide the basis of debate among conclusions whose inconsistencies cannot be definitively resolved. The causes of the fall of the Roman Empire furnish a question that traditionally has been offered as a basis for such debate.[208] The question whether natural selection furnishes a complete explanation of the origin of species or whether it requires supplementation by reference to irreducible complexity could become another—if it were allowed.

This question might provide a superior basis for the debate. Inquiry into the causes of the fall of the Roman Empire furnishes a magnificent question

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207. GRIFFIN, *supra* note 1, at 618 (first alteration in original) (citations omitted).

208. *See* Jay Tolson, *Lessons from the Fall*, U.S. NEWS & WORLD REP., May 7, 2007, at 28 (reporting on one historian's tally of 210 different explanations for the fall of Rome, as well as on the continuing American fascination with the question).

for the purpose, but it requires that the debaters know not only a great deal of history that is inaccessible to many people but also the methods of history. The natural-selection-versus-intelligent-design question, on the other hand, furnishes a basis for debate that is both inconclusive and amenable to some evidence that is readily at hand, even if sophisticated arguments require more depth. Legal arguments involve similar kinds of debate, and it seems likely that students who have been educated through this method would acquire skills that would serve them well in making or evaluating arguments about the law.

I. Teleology and Deontology

Finally, understanding the difference between teleology, which is illustrated by irreducible complexity theory, and deontology, which is analogous to natural selection, may help students to understand other philosophical questions. To see how, we must explore the fundamental ideas of ethical philosophy. This digression (and admittedly, it will create a long digression) will lead to what I contend is yet another secular purpose served by teaching irreducible complexity.

1. Teleology, Deontology, and Moral Concepts: There is a Great Divide in Ethical Philosophy Between Teleology and Deontology

Teleology is the philosophy that phenomena are not merely guided by mechanical forces but that they are purposive and move toward goals of improvement or self-actualization.[209] The most influential ethical thinkers in this realm are probably the great utilitarians, Jeremy Bentham and John Stuart Mill. The simplest statement of their philosophy is captured in Bentham's claim that "[t]he greatest happiness of the greatest number . . . is the measure of right and wrong," although there have been more sophisticated statements of the concept.[210] Deontology, on the other hand, describes an opposing class of philosophies that refuse to total costs and benefits from results.[211] The great philosopher here is Immanuel Kant, who denounced utilitarianism and set up an ethical system featuring "categorical imperatives": actions that could be imitated as "universal laws," never to be violated.[212] Thus, utilitarianism emphasizes "good" or "happiness," whereas Kantianism emphasizes "right" or "justice." There are other moral philosophies that do not conform to these descriptions, but these two types are dominant.

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209. *See* CRUMP, *supra* note 33, at 209–10.
210. *Id.* at 210–11.
211. *Id.* at 211–12.
212. *Id.*

Both philosophies are incomplete, however, in the sense that neither can explain a full range of moral choices in a manner that is satisfactory to modern thinking. Utilitarianism is "aggregative," meaning that it judges the morality of an action by totaling its results upon the happiness of all, even if the results are unequal, and even if some in the minority are made much less happy.[213] Kantian thinking, on the other hand, derives an "anti-objectification principle" as a categorical imperative: the notion that every human being has intrinsic worth and that it is never permissible for any human being to treat another solely as an object.[214] Thus, utilitarianism tends to justify the oppression of persons who already are oppressed. It even can be used to support slavery on the theory that unhappiness of some persons is moral if it leads to happiness in others so that the total of happiness increases.[215] The anti-objectification principle in Kantianism, of course, would firmly oppose this result.

But Kantianism is itself incomplete. Because it refuses to balance costs and benefits and instead depends upon nonnegotiable categorical imperatives, it drives moral decisions toward results that provide tiny benefits for some at great cost to others. Because keeping a promise is a categorical imperative, efficient breach is immoral, and a firm must keep its contract and bankrupt itself even for negligible benefit to the other contracting party.[216] Furthermore, Kant never told us what to do if two categorical imperatives conflict, as they tend to do for the hardest moral questions. Thus, if one has made a promise that turns out to be illegal, one must keep the promise and also obey the law because both actions are categorical imperatives. But it is impossible to do both if the two actions conflict. In this situation, the actor is left to "intuitionism," or idiosyncratic preference.[217] Utilitarianism avoids both of these traps by mandating the moral choice that does the least damage and preserves the greatest sum of happiness.

Thus, whether most people know it or not, they sometimes think in teleological moral terms and sometimes in deontological terms. The trick to leading a moral life, then, becomes a matter of knowing when to follow teleological thinking—and when to use deontology instead. Moral philosophers have proposed various tests to address this question, although

213. *Id.* at 211.
214. *Id.* at 212.
215. *Id.* at 213.
216. *Id.*
217. *Id.* at 213–14.

most of them contain major ingredients of intuitionism.[218] For example, Professor Heidi Hurd suggests that most questions should be resolved teleologically, by the utilitarian calculus, and that deontological thinking should be reserved for "patrol[ling] the borders" of moral choice.[219] In other words, one should think deontologically when utilitarianism leads to results that are offensive or "cross the line." In some areas of life, however, people may tend to be dominated by "right-wrong" thinking when they probably should consider the utilitarian balance.

2. From Moral Theories to Irreducible Complexity (or Vice Versa): How are These Questions of Moral Philosophy Relevant to the Study of Irreducible Complexity Theory?

There is an analogy between the divide that separates teleology and deontology in moral thinking and the related, but different, divide between philosophies in the natural world, i.e., science. In natural philosophy, teleology is the belief that there is evidence of design and purpose in nature.[220] With a difference that is subtle but important, teleology also can refer to the doctrine that final causes exist—for example, for the origins of the universe or for the presence of humankind. Irreducible complexity, of course, is a type of teleological philosophy. The evolutionist view, on the other hand, emphasizes natural selection. To understand natural selection, one must rigorously stamp out all vestiges of teleological thinking.[221]

The point is that it probably would be more practical to teach and learn the moral meanings of teleology and deontology if popular educations included the irreducible complexity critique of natural selection. Perhaps, in ages past when biology was taught differently, the philosophies of the utilitarians and the Kantians were better understood among educated people. Today, we have arguably improved our teaching of science but not of the methods of moral philosophy. Educated people do not necessarily understand these concepts, perhaps because their educations do not provide sufficient exposure to them. An interesting example is furnished by the way in which criminal justice courses in law schools cover the purposes or reasons for crime definition and sentencing. Some casebooks point out that three of the traditionally recognized factors—deterrence, incapacitation, and reform—are utilitarian, whereas the final factor, retributive justice, is deontological; but few casebooks supply any background about these

218. *Id.* at 220–22.
219. Heidi M. Hurd, *The Deontology of Negligence*, 76 B.U. L. REV. 249, 254 (1996).
220. *See* CRUMP, *supra* note 33, at 281.
221. *See supra* Part II.D.

philosophies.[222] To the extent that the casebooks do so, they cannot hope to connect these ideas to a widely shared background of understanding among students. The description comes off as a pair of labels, instead of as a philosophical framework that explains to students why they should consider both types of factors.

It should immediately be added that moral philosophy could be taught separately from biology, without the introduction of any idea contrary to natural selection in science classes. But I believe that the concepts would be better understood if the irreducible complexity critique were introduced and if the science class did not consist so one-sidedly of denunciations of all that is teleological. Therefore, I see better understanding of the great divide in moral philosophy as an additional secular purpose for considering intelligent design. I do not consider it the most important purpose because I see the development of science and its better understanding as more important, but it would furnish an added bonus.

IV. ESTABLISHMENT CLAUSE DOCTRINE: A BRIEF REVIEW

The discussion above of secular purposes is important as a policy debate, but it is more than that. It also proposes possible answers to one aspect of the constitutional question, which depends upon whether a policy of teaching intelligent design serves a secular purpose. But the answer to the constitutional question requires other inquiries as well. Therefore, the next step is to examine the Supreme Court's Establishment Clause doctrines.

A. The Lemon *Test, Its Inconsistent Development, and the Resulting Cross-Currents*

The first systematic framework for analyzing Establishment Clause claims was provided by *Lemon v. Kurtzman*.[223] The familiar *Lemon* test has three ingredients, requiring that a governmental action impinging upon religion (1) serve a "secular purpose," for which any non-religious purpose will do, with one such purpose being enough (the "purpose" prong); (2) avoid "primary effects" that either "advance" or "inhibit" religion (the "effects" prong); and (3) avoid any "excessive entanglement" with religion

222. *See, e.g.*, RONALD BOYCE ET AL., CRIMINAL LAW AND PROCEDURE 981–86 (10th ed. 2007) (containing a court opinion that applies the four factors, but with no surrounding material explaining the basis of utilitarian or Kantian philosophies).

223. 403 U.S. 602 (1971); *see also* Buckles, *supra* note 1, at 548–57 (discussing the constitutional authorities).

(the "entanglement" prong).[224] The *Lemon* test has the advantage of generality, and it seems to be based upon relevant issues. Its disadvantage is that it dissolves too easily into indeterminacy. Avoiding "effects" is difficult in a constitutional regime in which neither advancement nor inhibition is tolerable. Therefore, the real question becomes the following: How much and what kind of effect for or against religion is acceptable?[225] As for the entanglement prong, it begs the question by expressing the limit in terms of a prohibition upon "excessive" entanglement.[226]

Unfortunately, the rest of Establishment Clause doctrine is a system of cross-currents. There is a group of principles, some accepted by some justices and others accepted by other justices, that complete or substitute for the second and third prongs of the *Lemon* test. One approach is to expand the prohibition to cover any governmental action that "endorses" religion.[227] At its logical extreme, this view would prevent government from engaging in any action that might mention or depict religious ideas as acceptable. An opposing approach is to narrow the prohibition to government action that "proselytizes"[228] or, as a narrower alternative, "coerces."[229] The extreme of this approach would confine the Establishment Clause so that it would affect government conduct only if it overtly attempted to recruit citizens to religion (or alternatively, if it penalized them for refusing to accept it).

Then, there are the "accommodation" doctrines. These are of several kinds. In the first place, there must be accommodation of religion when the finding of an Establishment Clause violation would produce a violation of the Free Exercise Clause, which after all is part of the same Constitution.[230] The "wall of separation" metaphor, although picturesque, is not very useful because there are many circumstances in which government must be involved with religion to ensure free exercise or avoid discrimination against religion.[231] As Justice Douglas pointed out, otherwise a police officer could

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224. *Lemon*, 403 U.S. at 612–13.

225. *See* Mueller v. Allen, 463 U.S. 388, 396 (1983) (labeling this the "more difficult . . . question" and holding, but only by a 5–4 majority, that tax credits for tuition, textbooks, and transportation are constitutional even though they assist parochial education, partly on the grounds that "numerous private choices" are involved in the obtaining of funding, which also goes to secular schools).

226. *See* Bowen v. Kendrick, 487 U.S. 589, 591 (1988) (upholding, again by a 5–4 majority, government grants to religiously affiliated organizations to discourage premarital sex and pregnancy despite "specific incidents of impermissible behavior by grantees").

227. *See, e.g.*, County of Allegheny v. ACLU, 492 U.S. 573, 592–94 (1989) (plurality opinion).

228. *See, e.g.*, *id.* at 659–663 (Kennedy, J., concurring in the judgment in part and dissenting in part).

229. *See, e.g.*, Lee v. Weismann, 505 U.S. 577, 587 (1992); Santa Fe Indep. Sch. Dist. v. Doe, 530 U.S. 290 (2000).

230. *See* Sch. Dist. v. Schlempp, 374 U.S. 203, 296–299 (1963) (Brennan, J., concurring).

231. *See* Lynch v. Donnelly, 465 U.S. 668 (1984).

not guide traffic to and from a church, synagogue, or mosque.[232] Likewise, Justice Brennan observed that we otherwise would have to send soldiers to foreign wars without providing them with chaplains.[233] Second, there are symbols or communications whose historically religious origins are sufficiently remote so that readers are unlikely to see them as establishments of religion. The legend on our coins and bills, "In God we trust," has been given as an example.[234] Third, certain ceremonies that are religious in content can be accommodated in some places on the grounds that they are "traditional," such as prayers at the beginnings of legislative activities.[235] Fourth, seasonal observances, such as Christmas or Hanukkah displays, can be accommodated under certain circumstances. These displays are more likely to be permissible if they contain symbols from multiple religions.[236] Displays that include secular symbols as well as religious ones, such as those that include Disney characters along with crèches, also have an advantage in passing the test.[237] This last concept sometimes is pejoratively referred to as the "reindeer rule" on the theory that inclusion of a reindeer among religious symbols will sanitize an otherwise offensive religious display.[238]

This is a deliberately brief outline of a collection of conflicting doctrines that were developed by several other commentators and that often produce unpredictable results. In the context of the arguments about irreducible complexity, however, there is one further case that needs particular mention.

B. Edwards v. Aguillard *and the Invalidation of Louisiana's Creationism Act*

In *Edwards v. Aguillard*,[239] the Supreme Court invalidated Louisiana's Creationism Act. "Creation science" superficially resembled irreducible complexity theory because it also proposed examples of biological mechanisms that natural selection assertedly could not have produced.[240] It differed in that some of its proponents, unlike scientists who promote

232. *See* Zorach v. Clauson, 343 U.S. 306, 312 (1952).
233. *Schlempp*, 374 U.S. at 296–99 (Brennan, J., concurring).
234. *Id.* at 303.
235. *See* Marsh v. Chambers, 463 U.S. 783, 795 (1983).
236. *See, e.g.*, County of Allegheny v. ACLU, 492 U.S. 573 (1989).
237. *See* Lynch v. Donnelly, 465 U.S. 668 (1984).
238. *See* DAVID CRUMP ET AL., CASES AND MATERIALS ON CONSTITUTIONAL LAW 1129 (4th ed. 2002).
239. 482 U.S. 578 (1987).
240. *Id.* at 591.

theories of irreducible complexity, relied upon transparently religious elements.[241] There was a version that explained the diversity of flora and fauna in part by references to catastrophism as exemplified by a world-wide flood[242]—arguably, an allusion to the event that floated Noah's Ark. The Louisiana statute required the teaching of creation science whenever natural selection was taught, although it did not require the teaching of either.[243] It also provided certain protections and resources to teachers of creation science that it did not extend to teachers of evolution.[244] The stated purpose of the Act was to "protect academic freedom," and the implied purpose of the Act, at least as argued by Louisiana, was to advance "basic concepts of fairness" by "teaching all of the evidence."[245]

The Court, through Justice Brennan, concluded that the Creationism Act did not further its stated secular purposes.[246] Academic freedom usually is thought of as protecting choices by individual teachers, but this statute actually narrowed the available modes of teaching.[247] According to the Court, the statute also did not advance the goal of teaching all of the evidence because it provided incentives to the teaching of creation science that it did not provide to the teaching of evolution.[248] A law actually aimed at this asserted goal, said the Court, would encourage the teaching of "all scientific theories about the origins of humankind."[249]

Furthermore, in addition to failing the "purpose" prong, the Creationism Act failed the "effects" prong because it endorsed the religious belief that a supernatural being had created the universe. The legislative history convinced the Court that the term "creation science" was chosen to further precisely this goal.[250] Even worse, the Act was designed to prefer certain religious beliefs over others and to denigrate the teaching of a scientific theory that some religious sects disfavored but others did not.[251] The Court noted that the record included "uncontroverted affidavits" from scientists and others to the effect that "origin through abrupt appearance in complex form" was a true scientific theory; however, none of these affiants had contributed to the enactment of the law, and their opinions did not persuade the Court about either the meaning of the Act or its alleged secular

241. *Id.*
242. *Id.* at 600 (Powell, J., concurring).
243. *Id.* at 581 (citing LA. REV. STAT. ANN. § 17:286.4A (1982)).
244. *Id.* at 588 (citing LA. REV. STAT. ANN. § 17:286.7B (1982)).
245. *Id.* at 586.
246. *Id.* at 596.
247. *Id.* at 587.
248. *Id.* at 588.
249. *Id.*
250. *Id.* at 591–92.
251. *Id.* at 592–93.

purposes.[252] Justice Scalia, joined by Chief Justice Rehnquist, dissented on the ground that the case should be resolved after full consideration of the evidence, rather than by summary judgment.[253]

Edwards can be read to outlaw intelligent design, but it can also be distinguished. Intelligent design connotes the suggestion of a purposeful mechanism that can be read as paralleling the implication of a "Creator" in creation science,[254] although the theory does not depend upon a "designer," and although the suggestion from irreducible complexity is less necessarily religious.[255] Also, some of the groups most forcefully supporting irreducible complexity and intelligent design are, once again, those with certain religious viewpoints.[256] Furthermore, the Court's mention of the endorsement test in *Edwards*[257] may have facilitated its holding of unconstitutionality, and it presumably would cut in favor of the same result in an irreducible complexity case more than other tests might.

But on the other hand, the *Edwards* court did not consider the multiple secular purposes discussed above, which can be said to support the consideration of irreducible complexity theory. Instead, the Court narrowed its reading of the Creationism Act's possible secular purposes to those it inferred from legislative history—not the secular purposes that the Act could validly be said to advance, but only those that the legislature identified.[258] A law expressly founded on other, more achievable secular purposes might have a better chance of constitutional survival. Furthermore, if the Court were to apply a less restrictive test than the endorsement test, such as either the coercion or the proselytization approach,[259] it might reach a different result in its evaluation of the effects and entanglement prongs. Irreducible complexity theory is less easily viewed as focused upon a "Creator" than is creation science. Some scientists who promote irreducible complexity do not necessarily reject evolution, but rather see a case to be made for both theories.[260]

One also can consider the accommodation doctrines as supporting intelligent design on the basis of themes in these opinions that prefer

252. *Id.* at 595–96.
253. *Id.* at 610–11 (Scalia, J., dissenting).
254. *See supra* note 250 and accompanying text.
255. *See infra* Part V.C.2.
256. *See infra* Part V.C.1.
257. 482 U.S. at 593.
258. *See supra* notes 246–52 and accompanying text.
259. *See supra* notes 227–29 and accompanying text.
260. *See supra* note 23 and accompanying text.

government conduct that does not favor any identifiable religion or that pluralistically includes more than one major religion.[261] Intelligent design need not depend on any religious basis at all, although it fits comfortably with a wide variety of major world religions that propose a purposeful force behind the origin of species.[262] And finally, the Court's reference to teaching "all scientific theories about the origins of humankind"[263] arguably permits the introduction of irreducible complexity—unless, that is, this theory cannot claim to be "scientific."

V. IRREDUCIBLE COMPLEXITY AND THE ESTABLISHMENT CLAUSE

The key question in this area is often proposed by asking whether the introduction of irreducible complexity theory threatens values that are protected by the Establishment Clause. I would turn this question on its head by arguing that some approaches to natural selection can go too far and cause the inculcation of the theory to threaten values protected by the Establishment Clause, and I would ask whether it is possible that the introduction of irreducible complexity theory, as a critique, might reduce the threat to Establishment Clause values.

A. Can We Reduce the Tendency Toward an Establishment of Religion by Introducing Irreducible Complexity as a Critique of Natural Selection?

The teaching of natural selection requires such rigorous elimination of teleological thinking that it is not too much to assert that it puts the rejection of that thinking on the level of dogma.[264] Meanwhile, however, the possibility of a grand design that coincides with evolutionary observations cannot be eliminated by experiment or observation. A scientist can conclude that data have been collected that are consistent with an evolutionary hypothesis, but this is not the same as demonstrating that the data are inconsistent with a purposive force. Indeed, the adamant choice against teleology that accompanies the introduction of natural selection can be seen as exactly that—a choice. At the least, this is correct if the rejection of teleology is presented as a given, without debate, and without the development of the obvious contrary theory or its refutation.

The possibility exists, then, that the teaching of evolutionary theory can go farther than scientific inquiry and present itself as an alternative to religious doctrine. In fact, some scientists have suggested the deliberate substitution of natural selection for religion. Edward O. Wilson, the

261. *See supra* notes 230–37 and accompanying text.
262. *See supra* notes 199–200; *infra* Part V.C.2.
263. Edwards v. Aguillard, 482 U.S. 578, 588 (1987).
264. *See supra* Part II.D.

Pellegrino University Professor Emeritus at Harvard, is a scholarly giant in the fields of biodiversity and sociobiology. He treats the "scientific humanism" inherent in natural selection as an alternative to other religions—or, more accurately, as a religion itself:

> So, will science and religion find common ground, or at least agree to divide the fundamentals into mutually exclusive domains? A great many well-meaning scholars believe that such rapprochement is both possible and desirable. A few disagree, and I am one of them . . . . Rapprochement may be neither possible nor desirable. There is something deep in religious belief that divides people and amplifies societal conflict. In the early part of this century, the toxic mix of religion and tribalism has become so dangerous as to justify taking seriously the alternative view, that humanism based on science is the effective antidote, the light and the way at last placed before us.[265]

Professor Wilson follows this vision of scientific humanism (as "the light and way at last placed before us") and his recognition of the "dangerous" effects of "religion and tribalism" with some unusual arguments—unusual, that is, as reasons for accepting either science or faith.[266] Religion, he admits, has some positive effects.[267] It "has generated . . . the ideals of altruism and public service," and it has "inspired the arts."[268] Moreover, "[c]reation myths were in a sense the beginning of science itself."[269] But on the negative side, Professor Wilson points out that religion has created "bigotry and the dehumanization of infidels."[270] He then asks, "Can scientific humanism do as well or better [than theistic religions], at a lower cost?"[271] This has got to be the ultimate in pragmatism: we should replace theistic religions with Wilson's belief in secular humanism because he believes the change will result in a more positive social order! And Wilson is only one of many scientists who seek to persuade everyone to shed theistic religions and adopt atheism, agnosticism, or humanism.[272] It is no

265. Wilson, *supra* note 31, at 33.
266. *Id.*
267. *Id.*
268. *Id.*
269. *Id.*
270. *Id.*
271. *Id.*
272. *See* Jay Tolson, *The New Unbelievers: Books on Atheism Are Hot. But Do They Have*

longer possible to pretend, as the Supreme Court sometimes has,[273] that we do not inculcate secular humanism if we engage in a dogmatic denunciation of all that is teleological. The scientists' beliefs, and their efforts to proselytize people to them, are scientific, but they also are a religion.

The insistence upon non-teleological thought that is the basis of teaching natural selection implicitly eliminates the recognition of purposive forces behind the universe. It therefore could be taken as inconsistent with religious thought, which is inherently teleological. Professor Wilson reminds us that many scientists believe that rapprochement of science and religion is both possible and desirable.[274] But Professor Wilson's arguments take the issue into another realm altogether. "[S]cientific humanism," he writes, is "the only world-view compatible with science's growing knowledge of the real world and the laws of nature."[275] According to this view, natural selection is itself a religion, and on policy grounds, Professor Wilson suggests that it is quite possibly a healthier body of doctrine for human beings to accept. One senses, however, that Professor Wilson would not censor inquiry into the arguments underlying irreducible complexity because he advocates "[t]he shedding of blind faith [and the adoption of] intellectual fearlessness" that led Charles Darwin "to explore human evolution wherever logic and evidence took him."[276] These are thoughtful views, if iconoclastic.

Therefore, the rejection of teleology that often underlies the teaching of natural selection is troublesome if presented as a premise to be accepted without examination. Its counterpart is irreducible complexity, which furnishes an alternative premise. Without any examination of this alternative, the teaching of natural selection too easily becomes a matter of faith.[277] In Professor Wilson's view, and probably that of many others, natural selection may be a preferable substitute for religion. The formation of this belief is fine if it comes about in an individual independently of government inculcation.[278] But a government that teaches evolution by dogmatic insistence upon a non-purposive philosophy comes closer to an

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Anything Fresh to Say?, U.S. NEWS & WORLD REP., Nov. 13, 2006, at 40 (reporting that "books on atheism are hot"); David van Biema, *God vs. Science*, TIME, Nov. 13, 2006, at 48 (describing numerous books by scientists debunking God and calling for scientific substitutes).

273. The Supreme Court's treatment of this issue has been summary. "We agree . . . that the state may not establish a 'religion of secularism' . . . . We do not agree, however, that this decision in any sense has that effect." Sch. Dist. of Abington Twp. v. Schempp, 374 U.S. 203, 225 (1963). This approach is not viable today, given the views of many teachers like Wilson—assuming it ever was viable.

274. *See supra* note 265 and accompanying text.

275. Wilson, *supra* note 31, at 33.

276. *Id.*

277. *See supra* Part II.B.

278. *See* Wilson, *supra* note 31 and accompanying text.

establishment of religion than if it had recognized that there can be teleological explanations of the same phenomena. Furthermore, students can be left to infer this possibility if they are made aware of the irreducible complexity critique.

B. Applying Establishment Clause Criteria: Is It Lawful to Consider Irreducible Complexity?

As is the case in many Establishment Clause cases, the lawfulness of considering irreducible complexity in public schools depends not only on how the subject is presented and the context but which approach to the law is chosen. In other words, it depends upon which Supreme Court Justice the decisionmaker listens to.[279] Some approaches make the idea seem entirely likely to be constitutional, at least if it is presented without overt religious content, while others make that conclusion appear doubtful.

The *Lemon* test requires the application of three criteria: the purpose prong, the effects prong, and the entanglement prong.[280] The catalogue of secular purposes provided above addresses the purpose prong. *Edwards v. Aguillard*, which held Louisiana's Creationism Act unconstitutional for lack of any secular purpose, seems distinguishable because the theory of irreducible complexity, unlike Louisiana's Creationism Act, deals with subjects that current science cannot explain and has already spurred the development of new theories of natural selection.[281]

The effects prong and the entanglement prong, however, more often form the basis of constitutional decision. These criteria depend upon the overlay of interpretive theory that is chosen to test these issues. If a proselytization or a coercion approach is the true test, and if irreducible complexity is presented without overt content attributable to any particular religion, teaching irreducible complexity theory appears likely to be constitutional because presentation of the idea as a criticism of natural selection does not coerce or proselytize.[282]

If, on the other hand, an endorsement test[283] is thought to be the proper approach, the constitutionality of teaching irreducible complexity becomes more difficult to evaluate. On the one hand, irreducible complexity invites the conclusion that intelligent design is a factor in the origin of species—

279. *See supra* Part IV.
280. *See* Lemon v. Kurtzman, 403 U.S. 602 (1971).
281. *See supra* notes 7, 29 and accompanying text.
282. *Cf. supra* Part IV (discussing prosetylization and coercion approaches).
283. *Cf. supra* Part IV (discussing the endorsement test).

perhaps even requiring that conclusion. Then the effect is to suggest the action of a creative force underlying the universe. If this is enough to make out an endorsement of religion, then it can be argued that irreducible complexity cannot be raised as a theory without violating the Establishment Clause. On the other hand, teaching natural selection is constitutional in spite of its implicit endorsement of quasi-religious thinking in some people. If Professor Wilson is correct, and "scientific humanism" supplies the true "light and the way," the teaching of natural selection with an anti-teleological message presented as undisputed and unexamined fact leads to a religious effect just as surely as irreducible complexity does.[284] In fact, one can argue that the presentation of an alternative to that theory, such as irreducible complexity, would make the teaching of biology come closer to neutrality, in which government neither advances nor inhibits religion.

Finally, there is the entanglement prong,[285] which is subject to an analysis similar to that applied to the effects prong. Teaching irreducible complexity might require that the generation of books, lesson plans, or other materials be scrutinized to ensure that they do not contain explicitly religious content. Teachers of various religious or non-religious persuasions would need to be prevented from using irreducible complexity as an introduction to the Book of Genesis. On the other hand, the same concerns should apply today to the teaching of natural selection. Textbooks arguably should be scrutinized so that they avoid the suggestion that Professor Wilson sees as implicit in Darwinism: that scientific humanism is both logically compelled and preferable to any religion. Teachers presumably should be chosen and supervised so that they do not use evolutionary theory to denounce religion. The trouble is that the justification of this anti-religious bias is as easy to infer from natural selection theory, as Professor Wilson demonstrates,[286] as pro-religious bias is to infer from irreducible complexity. Viewed in this way, irreducible complexity does not produce an excessive entanglement with religion, and it arguably reduces that entanglement.

Then, too, one can consider accommodation doctrines as support for the teaching of irreducible complexity theory. In particular, the accommodation cases indicate that the presentation of ideas with religious suggestion can be constitutional if they are surrounded by, or presented in the context of, secular symbols.[287] The accommodation cases also illustrate that the Court is more likely to approve displays containing religious suggestion if multiple religions are included.[288] The introduction of irreducible complexity as a

284. Wilson, *supra* note 31, at 33.

285. *Cf. supra* Part IV (discussing the entanglement prong).

286. *See supra* notes 265–71 and accompanying text.

287. *See supra* Part IV (discussing Lynch v. Donnelly, 465 U.S. 668 (1984)).

288. *See supra* Part IV (discussing County of Allegheny v. ACLU, 492 U.S. 573 (1989)).

criticism of natural selection fits this description. I do not think the theory contains religious thought any more so than natural selection does, but even if it is thought of as quasi-religious, accommodation doctrine argues against the presentation of only the opposing view of natural selection. Discussion of irreducible complexity does not advance any particular religion, and in this regard, its introduction along with natural selection resembles the effect achieved by pluralistic Christmas displays or cross-and-menorah depictions. The "religious" suggestion, if any, is more a message of tolerance than an endorsement or proselytization.

C. *To What Extent Is the Debate Dependent Upon Mere Labels—or Upon the Private Beliefs of Supporters?*

1. The Potential Disenfranchisement of Religious People Who Make Secular Contributions

One Establishment Clause approach that has figured heavily in intelligent design cases is that the private religious beliefs or intentions of supporters of legislation ought to indicate unconstitutionality. Holdings striking down either creationism or intelligent design initiatives tend to offer, as purported support, the religious orientation of those who have lobbied for the teaching of these theories. For example, in *McLean v. Arkansas Board of Education*, the trial judge's opinion struck down an Arkansas statute partly on the ground that creationists were "inspired" by the story of the Creation in Genesis, and it dwelled heavily on the religiously oriented "views on the nature of creation science" held by Paul Ellwanger, who had formed a group supporting the teaching of this theory.[289] In *Kitzmiller v. Dover Area School District*, which invalidated a local school board resolution providing for the introduction of intelligent design into the curriculum, the trial judge emphasized the religious beliefs of Phillip Johnson, identified as the "father" of intelligent design, and of Professor Michael Behe, a theoretical biologist who has argued that natural selection cannot explain all phenomena without the addition of a theory of purposeful arrangements.[290] The judge also condemned the writings of The Discovery Institute for Renewal of Science and Culture on the ground that they "reveal[ed] cultural and religious goals" and not merely "scientific ones."[291]

289. 529 F. Supp. 1255, 1261–63 (E.D. Ark. 1982).
290. 400 F. Supp. 2d 707, 719–21 (M.D. Pa. 2005).
291. *Id.* at 720.

In an as-applied challenge, these items of evidence might be relevant. They should not have carried more than tangential weight, however, in a suit involving the facial invalidation of a state statute, as in *McLean*, or an entire school board policy, as in *Kitzmiller*. The fact is that many religious people have advanced the cause of science, as well as promoted other secular purposes, because they were inspired by religious belief. Pascal illustrated probability theory by his famous "Pascal's Wager": because the value of heaven was infinite, even if its probability seemed small, logic compelled the living of a life consistent with its existence.[292] Newton derived his mechanics, which are among the greatest achievements in physics, without experiment and with a firm grounding in his own religious beliefs.[293] These advancements should be viewed on their own terms, and not with reference to the religious philosophy of the inventors who developed them.

Nor should this principle be confined to the scientific realm. Imagine that a deeply religious philanthropist donates a hospital to a local government, stating publicly that he is doing so "for the greater glory of God." The reasoning in *McLean* and *Kitzmiller* suggests that the government might be forced to disclaim this gift on Establishment Clause grounds. That outcome is improbable; in fact, even if the mayor were to announce the donor's religious motivations publicly at a dedication ceremony, it seems odd to suggest that this hospital donation is unconstitutional. The Supreme Court has repeatedly recognized the argument that the Ten Commandments are a major precursor to modern moral sentiments underlying theories of government.[294] The religious origins of our penal codes, however, do not mean that they are unconstitutional. These portions of court opinions analyzing creationism and intelligent design cases represent sloppy thinking, and they pose a danger of disenfranchising religious people who make secular contributions.

2. Is "Irreducible Complexity" Perfectly All Right—While "Intelligent Design" is Unconstitutional?

Furthermore, there is the possibility that the entire controversy is nothing more than a dispute over mere words. In writing this piece, I was surprised by the responses of several reviewers who suggested that the teaching of a theory of irreducible complexity should not raise any substantial Establishment Clause objection. One reader even offered the possibility that irreducible complexity is a "straw man" in constitutional

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292. Wikipedia, Pascal's Wager, http://en.wikipedia.org/wiki/Pascal's_Wager (last visited Sept. 28, 2008).

293. *See supra* note 38 and accompanying text.

294. *See* Van Orden v. Perry, 545 U.S. 677, 688–90 (2005) (recognizing this argument and citing other cases that also recognize it).

terms. In other words, the propriety of teaching irreducible complexity is so clear that the legal question is trivial. Thus, the alleged offensiveness in the theory lies in the words—"intelligent design"—and in what they imply. If this view is correct, a teacher is on firm ground in covering the irreducible complexity critique of natural selection with students in a public school biology class. The teacher crosses the line, however, if the lesson develops the inexorable conclusion that irreducible complexity suggests purposeful design. But since irreducible complexity is a rebuttal to the random mutation process that underlies natural selection, the truth is that the one inevitably implies the other. Even if it is not a matter of syllogistic logic, the implication should be the subject of questions from inquisitive students. A mighty constitutional struggle, then, may come down to this: the teacher can suggest irreducible complexity but cannot suggest what it necessarily means, i.e., "purpose." One is tempted to think, "that can't be the law," but then again, many of us have thought that before—about propositions that did become the law, even though they depended upon mere wordplay.[295]

And perhaps the argument can be taken one step further. Perhaps the word "design" is constitutionally permissible. In this view, it is the word "intelligent" that provides the alleged offense. Design of one kind or another is to be found in many observed aspects of nature. For example, there is a "design" to the periodic table of elements, the table that is familiar to students of chemistry.[296] One can line up the elements by their atomic numbers in repeating rows, and if the chart is systematic, metals will appear on the left and noble gases on the right. One observes, over and again, that the columns and rows are surprisingly regular. When one reaches chlorine, for example, one finds it right below fluorine in the periodic table. Indeed, the two share many predictable characteristics, most notably the ready creation of ions with valence of negative one (-1). Furthermore, to the extent that these two related elements are different, the differences are also part of the "periodicity" (which is to say, the "design") of the table. For example, the smaller atom, fluorine, is more active than chlorine. The

295. *Compare, e.g.*, Mullaney v. Wilbur, 421 U.S. 684 (1975) (holding that the State *cannot* put the burden of proving "sudden passion" on defendant to reduce murder to manslaughter because the State had defined absence of passion as an element of the crime), *with* Patterson v. New York, 432 U.S. 197 (1977) (holding that the State *can* put the burden on the defendant if the State merely re-labels this factor as a defense).

296. *See generally* JOHN S. PHILLIPS ET AL., CHEMISTRY: CONCEPTS AND APPLICATION 92–93, 95–99, 102–07 (2002) (containing the periodic table and explaining the relationships between its classifications and the characteristics of elements).

pattern made by the table itself, its very periodicity, forms a visual chart, which conforms to an easily perceptible "design."

If a chemistry teacher were to refer to the "design" of the periodic table, it seems doubtful that the Establishment Clause constabulary would insist that the label is unconstitutional. Perhaps the same conclusion should apply if a biology teacher were to describe the "design" of the bacterial flagellum and offer irreducible complexity as a critique of natural selection. In fact, the very phrasing of "intelligent" design can be viewed as tautologous because "design" is inherently opposed to randomness and purposelessness, and it conveys the same sense of an underlying pattern. This reasoning may possibly mean that the Constitution poses no obstacle to a teacher telling students that irreducible complexity suggests "design," even if not "intelligent" design, even if the two are the same thing.

In fact, Wendell Bird, who has long championed creation science and intelligent design, has said as much. He has acknowledged that he used the creation-science label warily during the *Edwards* litigation only "because it was the language of the time," and today, he says he is "not fully comfortable with the [intelligent design] language, and would opt for something more secular."[297] Professor Leslie Griffin concludes from this observation that "[s]ecular language is more likely to fulfill a secular purpose."[298] One hopes that this Republic has judges somewhere who can avoid adjudication by mere labels, and who can avoid invalidating the secular contributions or criticisms offered by religiously motivated people. But then again, maybe not.

VI. CONCLUSION

My own conviction, then, is that intelligent design is an improbable explanation for the development of any aspect of the natural world, including the bacterial flagellum. After considering what biologists have to say about the issue, I personally believe that the flagellum developed through natural selection by the mechanism known as "exadaptation," meaning random mutations that led to a change in function of an existing organ. I think the most likely pathway is that its origins were in an excretory or secretory function, which could simultaneously and coincidentally have furnished a means of locomotion.[299] I would conjecture that while ridding itself of undesirable byproducts, the microorganism probably also incidentally expelled fluids that became propellants, and thus, as a

297. Leslie Griffin, *The Story of* Edwards v. Aguillard*: The Genesis of Creation-Science*, *in* EDUCATION LAW STORIES 303–318 (Michael A. Olivas & Ronna Greff Schneider eds., 2007).

298. *Id.* at 313.

299. This is the pathway suggested by Ian Musgrave. *See supra* notes 7, 29 and accompanying text.

consequence of the law of conservation of momentum, it found itself traveling in the opposite direction. It is not too much to suppose, then, that adaptation through a long series of mutations made for better locomotion by producing a means of controlling the resulting motion more precisely, such as the appearance of a cilium, or micro-hair, that enabled the bacterium to better steer toward nutrition or away from an inhospitable environment. And after that, the bearings, gears, universal joint, and corkscrew propeller may have emerged, also by accident, over billions of generations. I admit to having difficulty in surmising how the motor might have come about—the gradient of positive hydrogen ions that drives the gear that meshes with the flagellum shaft—but if the rest of these mechanisms could have developed through natural selection, I suppose the gradient motor could have too. In other words, the complexity of the flagellum may not be "irreducible." It may be subject to a persuasive theory that proposes a series of small, non-purposive steps, and someday, it may even be possible to test this hypothesis.

But I would not have wanted to come to these conclusions without considering the theories of irreducible complexity and intelligent design, which I believe are thoughtful and scientific. Even less would I want to find myself in a regime in which government presented natural selection as though irreducible complexity were a taboo subject. In other words, the censorship of irreducible complexity is not warranted by the Constitution or policy. The theory of natural selection would be better understood, the encouragement of new avenues of inquiry would remain more open, and the question—"What is science?"—would be more effectively taught if the theory of irreducible complexity were introduced as a criticism or alternative to the theory of evolution. The accommodation of this idea could readily be accomplished without overt religious content, which should not be suggested in the teaching of evolution either. Further, it could be accomplished with no more entanglement, religious effects, endorsement, coercion, or proselytization than accompanies the anti-teleological indoctrination that usually accompanies the teaching of natural selection.