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The Trouble with *Daubert-Kumho*: Reconsidering the Supreme Court's Philosophy of Science

David Crump[*]

"Scientific 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."
Sir Karl Popper, Conjectures and Refutations: The Growth of Scientific Knowledge,[1] *as cited in* Daubert v. Merrell Dow Pharmaceuticals, Inc.[2]

"[H]ypotheses non fingo (I don't generate hypotheses)."
Sir Isaac Newton, Principia Mathematica[3]

The Supreme Court has left the law of expert witnesses in a confused state. Its decision in *Daubert v. Merrell Dow Pharmaceuticals, Inc.*[4] was intended to liberalize the admittance of evidence,[5] but instead it has produced a minefield clogged with "*Daubert* hearings" that are more lengthy, technical, and diffuse than anything that preceded them.[6] Many judges have come to treat the factors

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1. (5th ed. 1989) at 37.

2. 509 U.S. 579, 593 (1993).

3. Cited in Dan Hunter, *No Wilderness of Single Instances: Inductive Inference in Law*, 48 J. LEGAL EDUC. 365, 380 (1998).

4. 509 U.S. 579 (1993).

5. *See infra* Part I.A. The Author uses the term "admittance" rather than "admission" to refer to the introduction of evidence to avoid confusion with the separate concept of "admissions" in evidence law.

6. In my own experience as a trial lawyer, a pretrial hearing to determine the admissibility of expert testimony was unusual before *Daubert*. It did not have a special name and, when it did appear, generally was raised through a separate device such as a motion in limine.

set out in *Daubert* not as flexible criteria, but as technical hurdles, tests to be rigorously surmounted.[7] One respected trial judge, for example, has churned out an exhaustive article that erects "eight gates" for expert witnesses.[8] Later, in *Kumho Tire Co. v. Carmichael*,[9] the Supreme Court recognized that the factors it had set out in *Daubert* to govern scientific evidence might fit other kinds of expert opinion poorly, but it nonetheless extended those very factors to the extent that they conceivably might apply, leaving the law in an even more indeterminate state. This trend has progressed so far, in fact, that a district court recently used *Daubert* and its progeny as grounds for altogether excluding fingerprint identification.[10] That court's reasoning seems to reflect an effort to apply the *Daubert* factors conscientiously, but the consequence seems simply to show that the law of expert opinion has lost its compass. (The court later reversed itself.)[11]

This Article is about one of the guideposts in the journey toward this result: the Supreme Court's definition of science. A major part of the problem, I believe, is that the *Daubert* Court's conceptual approach to the philosophy of science was unduly cramped. For example, if the Court's conception of science in *Daubert* were to be applied according to its terms, Sir Isaac Newton probably would be disqualified from testifying to a question within his competence.[12] The opinions of Sigmund Freud and Albert Einstein likely would meet the same fate.[13] Psychologist Howard Gardner, with his seven-typed theory of multiple intellectual competence, may have influenced our educational system profoundly, but if he were called to testify in a case within his claimed expertise, he would be vulnerable to the charge that his methods lack the specific indicia of scientific validity that the Supreme Court insisted upon in *Daubert*.[14] Perhaps these hypothetical experts are wrong about some of their conclusions, and there certainly are those who have no use for some of their theories.[15] But surely Newton, Freud, Einstein, and Gardner could "assist" a lay person in seeking the truth about their sciences. A trial by censorship of these kinds of opinions can be contemplated by imagining what the history of these great thinkers' disciplines would be like without them.

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7. *See, e.g., infra* notes 8, 10.

8. *See generally* Judge Harvey Brown, *Eight Gates for Expert Witnesses*, 36 HOUS. L. REV. 743 (1999).

9. Kumho Tire Co. v. Carmichael, 526 U.S. 137 (1999).

10. *See* United States v. Llera Plaza, 179 F. Supp. 2d 492 (E.D. Pa. 2002) (excluding prints), *vacated by* 188 F. Supp. 2d. 549 (E.D. Pa. 2002) (reversing exclusion of prints).

11. United States v. Llera Plaza, 188 F. Supp. 2d 549 (E.D. Pa. 2002).

12. *See infra* Part II.B.2.

13. *See infra* Part II.B.2-3.

14. *See infra* Part II.B.4.

15. *See infra* Part II.B.3 (discussing present-day attitudes toward the validity of Freud's work).

This Article begins with a brief exploration of the philosophy of science that is laid out in the *Daubert*, *Joiner*, and *Kumho* cases.[16] It then proceeds to examine the question, "what is science?" A related section considers the disadvantages and ironic results of the *Daubert-Kumho* definition of science.[17] Next, the Article considers the characteristics of a good scientific theory or model. It compares the resulting criteria to those set out in *Daubert* and its progeny and shows how the Supreme Court's philosophy can produce dubious consequences.[18]

A final section sets out my conclusions, which include the possibility that the Supreme Court could have avoided some of the confusion created in *Daubert* if it had confined itself to interpreting the rule that was at issue.[19] In short, the *Daubert* Court should have refrained from prematurely establishing detailed criteria until this area of law (and its own understanding of the problem) had matured. The Court's reading of Federal Rule of Evidence 702 as calling for "appropriate validation"[20] of scientific evidence provided a less treacherous guide to the lower courts, and that was where the *Daubert* opinion should have ended. Today, the lower courts could improve the law of expert opinion (and avoid silly results like excluding fingerprint identification) if they emphasized "appropriate validation" as the overarching test.[21]

I. THE *DAUBERT*, *JOINER*, AND *KUMHO* DECISIONS AND THE 2000 AMENDMENT TO RULE 702

Before *Daubert*, there was *Frye v. United States*,[22] which adopted a relatively rigorous and specific test that excluded all scientific evidence except that which had achieved "general acceptance" in the field of which it is a part.[23] *Frye* itself resulted in the exclusion of opinions derived from the use of a precursor to the polygraph. *Frye* did not affect non-scientific expert witnesses, however, and, therefore, financial witnesses, economists, and even physicians regularly testified without having to pass its hurdle.[24] Federal Rule of Evidence 702, without expressly rejecting the *Frye* test, adopted an alternate formulation: "If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue," an expert "may testify

16. *See infra* Part I.
17. *See infra* Part II.
18. *See infra* Part III.
19. *See infra* Part IV.
20. *See infra* Part I.A.
21. *See infra* Part IV.
22. 293 F. 1013 (D.C. Cir. 1923).
23. *Id.* at 1014.
24. *Id.* The decision was limited to "scientific principle[s] or discover[ies]." *Id.*

thereto."[25] Thus, the Rule covered "scientific . . . knowledge," but the criterion applied by the Rule was dependent upon whether the evidence would "assist" the jury.

The courts of appeals interpreted Rule 702 in ways that produced "sharp divisions."[26] Some erected higher barriers to scientific opinion testimony, others lower. It was against that background that the Supreme Court granted certiorari in *Daubert v. Merrell Dow Pharmaceuticals, Inc.* The case itself centered upon a claim that a Merrell Dow anti-nausea drug called Bendectin had caused birth defects.[27] The plaintiffs' experts had "re-analyzed" previously published epidemiological studies that had shown no causation of birth defects and had done in vitro and in vivo animal studies.[28] Both the district court and the court of appeals relied upon the *Frye* test to hold the plaintiffs' evidence inadmissible.[29] The Supreme Court granted certiorari to determine whether this traditional approach to scientific expert testimony was still correct.

A. Daubert v. Merrell Dow Pharmaceuticals, Inc.: *Science as "Falsifiability"*

The Supreme Court's first step in *Daubert* was to reject the *Frye* test on the ground that it was superseded by the adoption of the Federal Rules of Evidence.[30] The general thrust of the Federal Rules, the Court explained, was "a liberal one." The governing rule, Rule 702, did not embody the *Frye* test and was inconsistent with it. "The drafting history makes no mention of *Frye*, and a rigid 'general acceptance' requirement would be at odds with the 'liberal thrust' of the Federal Rules and their 'general approach of relaxing the traditional barriers to "opinion" testimony.'"[31] The Court characterized the *Frye* standard as "austere," a test that was absent from and "incompatible with" the Federal Rules, and held that it "should not be applied in federal trials."[32] Thus, the first message of *Daubert* is that scientific expert opinion is covered not by *Frye*, but by Rule 702, and it fits within a general policy of liberal admissibility.

Having established this policy of "relaxing" barriers to opinion testimony, however, the Court naturally felt the need to emphasize that there were limits. The first of these limits was that a scientific expert must be, in fact, testifying to

25. FED. R. EVID. 702.
26. Daubert v. Merrell Dow Pharm., Inc., 509 U.S. 579, 585 (1993).
27. *Id.* at 582.
28. *Id.* at 583.
29. *Id.* at 583-84.
30. *Id.* at 587.
31. *Id.* at 588.
32. *Id.* at 589.

"scientific . . . knowledge."[33] This phrase, said the Court, implied "a grounding in the methods and procedures of science." This meant that an inference offered in expert testimony "must be derived by the scientific method" and "must be supported by appropriate validation."[34]

Although the meaning of "appropriate validation" was not developed in the record before the Court and had not been decided below, Justice Blackmun proceeded to offer "some general observations."[35] The general observations were in the nature of an advisory opinion,[36] but the Court did not discuss that issue. It declared that "a key question to be answered in determining whether a theory or technique is scientific knowledge that will assist the trier of fact" would be "whether it can be (and has been) tested."[37] The Court then quoted philosopher Karl Popper: "Scientific methodology . . . 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."[38] And the Court added other authorities: "[T]he statements constituting a scientific explanation must be capable of empirical test";[39] and "[t]he criterion of the scientific status of a theory is its falsifiability, or refutability, or testability."[40] To this first, "key" criterion, the Court added three others: peer review and publication, known or potential rate of error, and a concept of general acceptance that mirrored the *Frye* test but was not to be used as the sole criterion.[41] The Court emphasized that the inquiry was to be "a flexible one,"[42] and its advisory list of questions was not presumed to be "definitive."[43]

The Court mentioned at least two other requirements for scientific evidence. The targeted scientific principle must not only be scientific, but it must "relate

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33. *Id.* at 589-90.

34. *Id.* at 590.

35. *Id.* at 592-93.

36. An advisory opinion answers questions that are not dispositive of the case presented. Strictly speaking, the general observations may not have been an advisory opinion because they had at least the possibility of becoming determinative at some point. They were in the nature of an advisory opinion, however, in that they had not been preceded by lower court development, were not the subject of the grant of certiorari, and were not the focus of the parties' briefing, since the issue was the viability of the *Frye* test.

37. *Daubert*, 509 U.S. at 593.

38. *Id.* (quoting E. GREEN & C. NESSON, PROBLEMS, CASES AND MATERIALS ON EVIDENCE 645 (1983)).

39. *Id.* (quoting C. HEMPEL, PHILOSOPHY OF NATURAL SCIENCE 49 (1966)).

40. *Id.* (quoting K. POPPER, CONJECTURES AND REFUTATIONS: THE GROWTH OF SCIENTIFIC KNOWLEDGE 37 (5th ed. 1989)).

41. *Id.* at 593-94.

42. *Id.* at 594.

43. *Id.* at 593.

to" a fact at issue. The Court described this issue as one of "fit."[44] Scientific testimony about phases of the moon, for example, might provide helpful information about whether a certain night was dark, and if darkness in fact was in dispute, the knowledge would "assist" the jury; but if the issue was whether an individual "was unusually likely to have behaved irrationally on that night," in the manner of, say, a werewolf, the moon-phase evidence would not "fit" the issue.[45] Logically, this werewolf inquiry must be done as a separate and probably second inquiry, after the evidence is established as scientific. Furthermore, the Court held that Rule 403[46] must govern scientific opinion, just as it governs all evidence. Thus, even if the evidence had some claim to the label of science, and even if it arguably fit, if the resulting "probative value" was "substantially outweighed" by the danger of unfair prejudice, confusion, or danger of misleading the jury, it should be excluded.[47] But the focus, said the Court, "of course, must be solely on principles and methodology, not on the conclusions that they generate," so that it was possible for scientific opinion to be debatable, or even to be opposed to other scientific evidence or opinion, without being excluded.[48]

The Court concluded with a brief mention of "conventional devices" for testing evidence.[49] It also expressed confidence in trial judges, in "the capabilities of the jury," and in "the adversary system generally."[50] Thus, "[v]igorous cross-examination, presentation of contrary evidence, and careful instruction on the burden of proof are the traditional and appropriate means of attacking shaky but admissible evidence."[51] Additionally, "the [trial] court remains free to direct a judgment . . . and likewise to grant summary judgment."[52] These traditional processes, "rather than wholesale exclusion," were the appropriate safeguards in the case of scientific evidence.[53]

Chief Justice Rehnquist, joined by Justice Stevens, dissented in part. The gist of his opinion was expressed in this conclusion: "I think the Court would be far better advised in this case to decide only the questions presented, and to

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44. *Id.* at 591.

45. *Id.*

46. Federal Rule of Evidence 403 states: "Although relevant, evidence may be excluded if its probative value is substantially outweighed by the danger of unfair prejudice, confusion of the issues, or misleading the jury, or by consideration of undue delay, waste of time, or needless presentation of cumulative evidence."

47. *Daubert*, 509 U.S. at 595.

48. *Id.*

49. *Id.* at 596.

50. *Id.*

51. *Id.*

52. *Id.*

53. *Id.*

leave the further development of this important area of the law to future cases."[54] "I defer to no one in my confidence in federal judges," the Chief Justice went on to say, "but I am at a loss to know what is meant when it is said that the scientific status of a theory depends on its 'falsifiability,' and I suspect some of them will be, too."[55] A judge's duty, he thought, was not "to become [an] amateur scientist[]."[56]

With respect to the "general observations" made by the Court, Chief Justice Rehnquist observed that such observations customarily "carry great weight with lower federal courts."[57] The question, however, was whether they should: "they tend to be not only general, but vague and abstract."[58] Furthermore, "even if it were desirable to make 'general observations' not necessary to decide the questions presented, I cannot subscribe to some of the observations made by the Court."[59] This objection extended to the Court's discussion of "appropriate validation."[60] Thus, Chief Justice Rehnquist questioned whether the phrase, "scientific, technical, or other specialized knowledge," should "be broken down into numerous subspecies of expertise, or [whether] its authors simply pick[ed] general descriptive language covering the sort of expert testimony which courts have customarily received."[61]

This Article argues that the majority's effort to answer prospectively the question, "what is science?" was not only uncalled for by the case before it but was also unwise and dysfunctional in its result.

B. General Electric Co. v. Joiner: *Do the "Conclusions" Need to Be Scientific, or Only the "Principles and Methodology"?*

The *Joiner*[62] case concerned experts relied upon to support the plaintiff's contention that exposure to PCBs had contributed to his cancer. Studies in infant mice had shown that massive doses of PCBs could cause cancer of a different variety than Joiner's. A district court held this foundation inadequate to satisfy the *Daubert* requirements and excluded the testimony. The Supreme Court upheld the exclusion.[63]

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54. *Id.* at 601 (Rehnquist, C.J., dissenting).
55. *Id.* at 600 (Rehnquist, C.J., dissenting).
56. *Id.* at 601 (Rehnquist, C.J., dissenting).
57. *Id.* at 598 (Rehnquist, C.J., dissenting).
58. *Id.* (Rehnquist, C.J., dissenting).
59. *Id.* at 599 (Rehnquist, C.J., dissenting).
60. *Id.* at 599-600 (Rehnquist, C.J., dissenting).
61. *Id.* (Rehnquist, C.J., dissenting).
62. Gen. Elec. Co. v. Joiner, 522 U.S. 136 (1997).
63. *Id.* at 146.

The gist of the Supreme Court's reasoning was that this kind of trial court decision about admissibility could be reversed only for abuse of discretion.[64] Furthermore, "[the plaintiff's expert's animal] studies were so dissimilar to the facts presented in this litigation that it was not an abuse of discretion for the district court to have rejected the expert's reliance on them."[65] But the Court went on to describe the way in which a district court might consider "bad" scientific conclusions inadmissible:

> Respondent points to *Daubert*'s language that the "focus, of course, must be solely on principles and methodology, not on the conclusions that they generate." . . . He claims that because the District Court's disagreement was with the conclusion that the experts drew from the studies, the District Court committed legal error and was properly reversed by the Court of Appeals. But conclusions and methodology are not entirely distinct from one another. Trained experts commonly extrapolate from existing data. But nothing in either *Daubert* or the Federal Rules of Evidence requires a district court to admit opinion evidence which is connected to existing data only by the ipse dixit of the expert. A court may conclude that there is simply too great an analytical gap between the data and the opinion proffered. That is what the District Court did here, and we hold that it did not abuse its discretion in so doing.[66]

Justice Stevens again dissented in part. He believed that the Court should have confined itself to stating that abuse of discretion was the proper standard, without confusing conclusions with principles and methodology.[67] Furthermore, the record did not include each of the scientific studies upon which the plaintiff had relied, nor had the district court discussed all of them.[68] "Whether a fair appraisal of either the methodology or the conclusions of Joiner's experts can be made on the basis of such an incomplete record is a question that I do not feel prepared to answer."[69] But for Justice Stevens, the real question was a deeper one:

> The [lower court's] discussion of admissibility is faithful to the dictum in *Daubert* that the reliability inquiry must focus on methodology, not conclusions. Thus, even though I fully agree with both the District

64. *Id.* at 144-45.
65. *Id.*
66. *Id.* at 146 (Stevens, J., dissenting).
67. *Id.* at 151 (Stevens, J., dissenting).
68. *Id.* (Stevens, J., dissenting).
69. *Id.* (Stevens, J., dissenting).

> Court's and this Court's explanation of why each of the studies on which the experts relied was itself unpersuasive, a critical question remains unanswered: when qualified experts have reached relevant conclusions on the basis of an acceptable methodology, why are their opinions inadmissible? *Daubert* quite clearly forbids trial judges from assessing the validity or strength of an expert's scientific conclusions, which is a matter for the jury. Because I am persuaded that the difference between methodology and conclusions is just as categorical as the distinction between means and ends, I do not think the statement that "conclusions and methodology are not entirely distinct from one another," is either accurate or helps us answer the difficult admissibility question presented by this record. In any event, it bears emphasis that the Court has not held that it would have been an abuse of discretion to admit the expert testimony.... And nothing in either *Daubert* or the Federal Rules of Evidence requires a district judge to reject an expert's conclusions and keep them from the jury when they fit the facts of the case and are based on reliable scientific methodology.[70]

Justice Stevens would have remanded the case without deciding it.[71]

The controversy about conclusions and their relationship to principles and methodology is indicative of the confused state of the law of expert opinion. Arguably, it is dangerous to throw out a result—a conclusion—that follows from proper reasoning simply because it seems outlandish.[72] For that matter, it may be difficult for the non-scientist to tell whether a scientist has created "too great an analytical gap." Accepted scientific opinion at one point in history had the sun traveling around the earth, and it seems unlikely that a Newtonian analysis of falling apples could have persuaded a papal curia to think differently.[73] The

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70. *Id.* at 154-55 (Stevens, J., dissenting) (footnotes omitted).

71. *Id.* at 151 (Stevens, J., dissenting).

72. This holistic method of decision is vulnerable to bias. For example, "anchoring" is a psychological fallacy that consists of clinging to early conclusions and failing to adjust them for new data that point to a new conclusion because the older conclusion is preferred. *See, e.g.*, Amos Tversky & Daniel Kahneman, *Judgment Under Uncertainty: Heuristics and Biases*, 185 SCIENCE 1124 (1974); DAVID CRUMP, HOW TO REASON: INTERDISCIPLINARY APPROACHES TO THE FOUNDATIONS OF PUBLIC POLICY § 2.02(C) (2002). On the other hand, holistic approaches can be important heuristics for detecting error in deductive logic. The point is that it must be consulted with skepticism. *Id.* § 2.03(B); DOUGLAS WALTON, A PRAGMATIC THEORY OF FALLACY ch. 1 (1995).

73. The reference is, first, to Newton, who is said to have deduced the principle of gravitation after observing the fall of an apple. WILLIAM STUCKLEY, MEMOIRS OF SIR ISAAC NEWTON'S LIFE 19-20 (1752) (Taylor & Francis ed., 1936). Second, Galileo was convicted by the papal curia of heresy for allegedly maintaining the concept that the earth

lazy mind might tend to see too great an analytical gap between apples and astronomy. And in the next case—*Kumho Tire*—it is arguable that that is what the Supreme Court did.

C. Kumho Tire Co., Ltd. v. Carmichael: *Generalizing the "General Observations"*

The claim in *Kumho*[74] was that the defendant's tire was defective. The plaintiff's expert, Carlson, offered the conclusion that a defect had caused the inner steel-belted carcass to separate from the tread.[75] Carlson's method and principles were confusing. First, he said that if the separation was not caused by a kind of misuse called "overdeflection," then ordinarily its cause was a tire defect.[76] Second, he said that if a tire has been subjected to sufficient overdeflection to cause a separation, it should reveal certain physical symptoms.[77] Third, he explained his methodology: where he did not find at least two of four physical signs, he concluded that a manufacturing or design defect had caused the separation.[78] The situation was further complicated by the presence of the questioned physical symptoms to a limited degree, but Carlson explained why, in each instance, the symptoms were neither significant or indicative of overdeflection.[79] Therefore, Carlson concluded that because the tire did not bear at least two of the overdeflection symptoms, overdeflection had not caused the blowout, and a defect must have done so.[80]

The district court examined Carlson's methodology in light of the reliability-related factors that *Daubert* had mentioned, including testability, peer review or publication, rate of error, and degree of acceptance.[81] The court conceded that there might be widespread acceptance of a "visual-inspection method," but it found insufficient indications of the reliability of Carlson's

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moved about the sun. *See* CRUMP, *supra* note 72, at 309. Third, the connection between particles such as the earth and the apple, which obviously displayed "too great an analytical gap" for the papal curia to traverse, was developed by both Galileo and Newton, *see* RONALD LANE REESE, UNIVERSITY PHYSICS 173 (Keith Dodson & Beth Wilbur eds., 2000), and it helped explain Kepler's laws of planetary motion. *See id.* at 244-54. The point is that whether an inference bridges too great an analytical gap is a difficult question for a court trying to perform amateur science, as the court that convicted Galileo demonstrated.

74. Kumho Tire Co. v. Carmichael, 526 U.S. 137 (1999).

75. *Id.* at 143.

76. *Id.* at 144.

77. *Id.*

78. *Id.*

79. *Id.* at 144-45.

80. *Id.* at 145.

81. *Id.*

analysis.[82] Pursuant to *Daubert*, the district court excluded Carlson's evidence.[83] The Eleventh Circuit Court of Appeals, however, reversed, holding that the evidence should have been admitted.[84]

The Supreme Court reversed the Eleventh Circuit's reversal and reinstated the district court's decision excluding the evidence.[85] It did so, in part, on the basis of the abuse of discretion standard,[86] but it carried the issue far beyond that principle. In fact, the *Kumho* opinion, like *Daubert*, is remarkable for the degree to which the Court decided questions not presented by the record. First, the Court decided that Rule 702 "makes no relevant distinction between 'scientific' knowledge and 'technical' or 'other specialized' knowledge. It makes clear that any such knowledge might become the subject of expert testimony."[87] Furthermore, "[w]e concede that the Court in *Daubert* referred only to 'scientific knowledge.' But as the Court there said, it referred to 'scientific' testimony 'because that [wa]s the nature of the expertise at issue.'"[88] It would prove "difficult, if not impossible" for judges to distinguish between "scientific" knowledge and "technical" or "other specialized" knowledge, and there was no "convincing need" to make such distinctions.[89] Therefore, said the Court, "[w]e conclude that *Daubert*'s general principles apply to the expert matters described in Rule 702."[90]

In making these observations, the Court did not recount the sharp lines it had drawn in *Daubert*. There, in black and white, the Court had explained its holding by reference to falsifiability: "this methodology is what distinguishes science from other fields of human inquiry."[91] Having made this "distinction" a matter of emphasis in *Daubert*, the *Kumho* Court, with surprising facility, reached the conclusion that no distinction was necessary.[92] The Court's reasoning that "[t]here is no clear line that divides" the one (science) from the others (technical or "other specialized" knowledge)[93] also provided only dubious support for its conclusion. The absence of a "clear line," presumably, did not necessarily mean that there was no distinction at all; frequently, in fact, it is the

82. *Id.* at 146.
83. *Id.* at 145.
84. *Id.* at 146.
85. *See id.* at 158.
86. *Id.* at 152.
87. *Id.* at 147.
88. *Id.* at 147-48.
89. *Id.* at 148.
90. *Id.* at 149.
91. Daubert v. Merrell Dow Pharm., Inc., 509 U.S. 579, 593 (1993).
92. *Kumho*, 526 U.S. at 147-48.
93. *Id.* at 148.

Court's duty to make distinctions where there are no clear lines.[94] The Court's conclusion that there was no "convincing need" for such a distinction rested primarily upon the observation that both types of experts rely upon "specialized theory" that is "confessedly foreign" to the judiciary.[95] These superficial resemblances seem a gossamer basis for dispensing with distinctions. Nevertheless, the Court reached the result that way: "[w]e conclude that *Daubert*'s general principles apply to the expert matters described in Rule 702."[96]

Next, the Court took another logical leap. Because *Daubert*, in analyzing scientific testimony, had set out four factors, those four factors should apply, also, to other kinds of specialized knowledge. Thus, testability, peer review and publication, rate of error, and general acceptance all were factors to be applied not just to scientific testimony, but to other kinds of evidence governed by Rule 702.[97]

Having thus stated that *Daubert* applies even to non-*Daubert* witnesses, the Court backtracked:

> We agree with the Solicitor General that "[t]he factors identified in *Daubert* may or may not be pertinent in assessing reliability, depending on the nature of the issue, the expert's particular expertise, and the subject of his testimony." The conclusion, in our view, is that we can neither rule out, nor rule in, for all cases and for all time the applicability of the factors mentioned in *Daubert*, nor can we now do so for subsets of cases categorized by category of expert or by kind of evidence. Too much depends upon the particular circumstances of the particular case at issue.[98]

At this point in the opinion, the Supreme Court had stated that *Daubert*'s criteria were pertinent in assessing reliability, but might not be pertinent in assessing reliability. The Court went on to emphasize the flexibility of the *Daubert* holding, which would permit an expert to testify even though the opinion had never been the subject of peer review, for example.[99] The Court then introduced two examples—an engineer and a perfume sniffer:

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94. In his concurrence in *Bendix Autolite Corp. v. Midwesco Enters.*, 486 U.S. 888 (1988), for example, Justice Scalia aptly described the Court's task as analogous to deciding "whether a particular line is longer than a particular rock is heavy." *Bendix*, 486 U.S. at 897 (Scalia, J., concurring).

95. *Kumho*, 526 U.S. at 148-49.

96. *Id.* at 149.

97. *Id.* at 149-50.

98. *Id.* at 150.

99. *Id.* at 151.

> [S]ome of *Daubert*'s questions can help to evaluate the reliability even of experience-based testimony. In certain cases, it will be appropriate for the trial judge to ask, for example, how often an engineering expert's experience-based methodology has produced erroneous results, or whether such a method is generally accepted in the relevant engineering community. Likewise, it will at times be useful to ask even of a witness whose expertise is based purely on experience, say, a perfume tester able to distinguish among 140 odors at a sniff, whether his preparation is of a kind that others in the field would recognize as acceptable. We do not believe that Rule 702 creates a schematism that segregates expertise by type while mapping certain kinds of questions to certain kinds of experts. Life and the legal cases that it generates are too complex to warrant so definitive a match.[100]

Even given this amorphous standard, said the Court, *Daubert*'s "gatekeeping requirement" was "importan[t]."[101]

The Court's method of dealing with the inherent contradictions in what it had said was to blur the lines: "we conclude that the trial judge must have considerable leeway in deciding in a particular case how to go about determining whether particular expert testimony is reliable."[102] And if that was not confusing enough, the Court added: "a trial court should consider the specific factors identified in *Daubert* where they are reasonable measures of the reliability of expert testimony."[103]

The Court finally shifted to analyzing Carlson's testimony regarding the allegedly defective tire. The Court emphasized that the basis for Carlson's conclusion was not simply "the general theory that, in the absence of evidence of abuse, a defect will normally have caused a tire separation. Rather, the expert employed a more specific theory to establish the existence (or absence) of such abuse. Carlson testified precisely that in the absence of *at least two* of four signs of abuse, . . . he concludes that a defect caused the separation."[104] Thus, the expert explained the steps he had followed in a way that the jury could probably evaluate as readily as the judge. The Court, however, excluded the evidence without focusing on the jury's competence. Perhaps the most significant justification for the Supreme Court's holding was the same as that for the district court, "that 'none' of the *Daubert* factors, including that of 'general acceptance'

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100. *Id.*
101. *Id.* at 152.
102. *Id.*
103. *Id.*
104. *Id.* at 154.

in the relevant expert community, indicated that Carlson's testimony was reliable."[105]

The Court could have taken a different route, one more consistent with *Daubert*'s holding that scientific evidence is distinguishable. It could have held that non-scientific experts are not subject to the four-part *Daubert* factors. It could have recognized that what it called "experienced based" experts derive and express their opinions in a manner quite different from scientific reasoning. The perfume sniffer, for example, uses observation as the basis of expertise, observing just as a bystander observes an automobile accident. Arguably, it makes no more sense to ask the expert perfume sniffer about methods and principles for distinguishing perfumes than it does to ask the accident witness what methods and principles are used to distinguish a Ford from a Chevrolet, or a red light from a green one. Asking a bystander whether the distinction between green and red is testable, peer reviewed, subject to a known error rate, or generally accepted is analogous to asking the same questions of the perfume sniffer.

Furthermore, the perfume sniffer does not purport to use science or theory. In assessing the credibility of such an expert, the jury is in approximately the position it occupies when judging the testimony of any witness who has observed a detail through one of the five senses.

D. The 2000 Amendment to Rule 702: How the Procrustean Bed Became Cast in the Concrete of an Enactment

In 1999, the Judicial Conference's Advisory Committee on the Federal Rules of Evidence proposed an amendment to Rule 702. The amendment has been referred to as "effectively codify[ing]" the *Kumho* approach:

> Rule 702. Testimony by Experts
>
> If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise *if (1) the testimony is based upon sufficient facts or data, (2) the testimony is the product of reliable principles and methods, and (3) the witness has applied the principles and methods reliably to the facts of the case.*[106]

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105. *Id.* at 156.

106. FED. R. EVID. 702 (emphasis added). *See* PAUL F. ROTHSTEIN, MYRNA S. RAEDER & DAVID CRUMP, SUPPLEMENT TO EVIDENCE: CASES, MATERIALS AND PROBLEMS 46 (1999) (asserting that the amendment effectively codifies *Kumho*).

This amendment became effective on December 1, 2000.[107]

The thesis of this Article is that this amendment was undesirable. First, for reasons that appear below, it was undesirable to codify *Kumho*'s adoption of *Daubert*, because *Daubert* reflects an inappropriately narrow conception of science.[108] Furthermore, an effort to codify a case with as many contradictory nuances as *Kumho*, when it is based upon another opinion that is based upon the Rule being amended, is likely to fail to capture all of those nuances.

And perhaps a bigger problem lies in the application of the added portion of the Rule to experience-based experts. Consider a dirt-under-the-fingernails expert such as a garage mechanic, who testifies about carburetor malfunctions or the reasonable cost of repairs and is asked whether the underlying "principles" were "peer reviewed," or are "falsifiable," or produce known "error rates." Try asking the same questions of a teenager testifying to the meaning of youth-gang terminology. Furthermore, imagine the application of the amended Rule to the perfume sniffer:

> Q: Mr. Perfume Sniffer, the Supreme Court says that I must first ask you whether (1) your testimony identifying perfumes by the nasal method is based upon "sufficient facts or data."
> A: Well, I sniffed the perfume. Is that "sufficient facts or data?"
> Q: And (2) I have to ask you whether your testimony is the product of "reliable principles and methods."
> A: Look. I smelled Chanel No. 5. I know I smelled Chanel No. 5.
> Q: And did you "apply the principles and methods reliably to the facts of the case?"
> A: I used my nose. That's all I can do.

The Rule requires consideration of these criteria, ostensibly for every expert witness and, unlike *Daubert* and *Kumho*, it does not itself express any flexibility.[109]

The Advisory Committee's note reflects wishful thinking about this issue:

> Nothing in this amendment is intended to suggest that experience alone . . . may not provide a sufficient foundation for expert testimony. In certain fields, experience is the predominant, if not sole, basis for a great deal of reliable expert testimony . . . .
>
> If the witness is relying solely or primarily on experience, then the witness must explain how that experience leads to the conclusion reached, why that experience is a sufficient basis for the opinion, and

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107. FED. R. EVID. 702.
108. *See infra* Parts II-III.
109. *See* FED. R. EVID. 702.

> how that experience is reliably applied to the facts. . . . The more subjective and controversial the expert's inquiry, the more likely the testimony should be excluded as unreliable. . . .[110]

Judges and lawyers can be forgiven, however, if they focus upon the language of the Rule, which is positive law, and which unfortunately requires a demonstration that the testimony "is the product of reliable principles and methods," not merely of "experience."[111] The Rule text, of course, overrides the Advisory Committee's note.[112] And the Rule requires what it requires of every expert witness, however outlandish that may be. Furthermore, the perfume sniffer cannot reproduce objective indicia of the opinion in the courtroom, and, therefore, in the terminology of the Advisory Committee, offers "subjective and controversial" opinions of the kind that the Advisory Committee says should be especially likely to be "excluded as unreliable."[113] The Procrustean bed created by *Daubert* and *Kumho*, thus, has been cast in the concrete of an enacted Rule.

The sections that immediately follow will emphasize expert scientific evidence. They will consider whether the Supreme Court's definition of science is too narrow. The primary focus is on *Daubert* rather than *Kumho*. But in later sections, dealing with methodology and principles, the Article will consider the difficulties inherent in the *Kumho* holding as well.

II. WHAT IS SCIENCE?

A. Scientific Method: Observation, Concept, and Quantitative Theory

What is science, and what makes a proposition more or less "scientific"? In this Part, I shall argue that there are at least three parts of the scientific endeavor: observation, concept, and quantitative theory.[114] Throughout the history of science, different ones of these three issues have been pushed to the forefront, and they have been the battleground of the philosophy of science.[115]

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110. FED. R. EVID. 702 advisory committee's notes.

111. *See* FED. R. EVID. 702.

112. *See* Daubert v. Merrell Dow Pharm., Inc., 509 U.S. 579, 587 ("We interpret the legislatively-enacted Federal Rules of Evidence as we would any statute.").

113. FED. R. EVID. 702 advisory committee's notes.

114. *See* CRUMP, *supra* note 72, at 301-15 (discussing the meaning of science and the characteristics of a good scientific theory).

115. *See* CRUMP, *supra* note 72, at 301-15.

1. Science as Observation: The Empiricists or Positivists

To some philosophers, the empiricists or logical positivists, observations are the defining characteristic of science.[116] In this view, a concept or theory—for example, Boyle's Law relating to the pressure, temperature, and volume of a gas[117]—always is inaccurate. In fact, this criticism is literally true of any scientific theory. To use the same illustration, Boyle's Law applies only to an "ideal" gas, a hypothetical concept that does not really exist but was invented by theoreticians so that the numbers for Boyle's Law would work out.[118] (Boyle's Law is that $P_1 \times V_1/T_1 = P_2 \times V_2/T_2$, or the pressure of a gas multiplied by the volume and divided by the temperature is constant.)[119]

For empirical philosophers, science consists of measurement, observation, and experimentation.[120] A slavishly literal empiricist might say that a concept such as Boyle's Law, which produces only approximations when used with real gases such as oxygen or ammonia, is unscientific because experimentation proves that although it gives approximations, it always gives false values. It ultimately requires empirical observation anyway, to tell what the real numbers are. Although few empiricists would push the primacy of observation to the point of rejecting Boyle's Law, this example may show why the empiricists must, at some point, compromise with conceptualists if we are to avoid conceiving of science merely as a jumble of unrelated observations.

Thus, the empiricists see experiment as the core of science. Experimentation or observation, with measurement, can exhibit consistency with (and inductively support) a theoretical relationship, or it can disprove (or "falsify") it. This relatively narrow view limits science to that which is "falsifiable."[121] The British-Austrian philosopher Sir Karl Popper has been a leading proponent of this view of "generating hypotheses" that can be "tested" empirically, or of science as defined by "falsifiability." The famous quotation from Popper that appears at the beginning of this Article is the linchpin of the Supreme Court's opinion in *Daubert*.[122]

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116. MORRIS RAPHAEL COHEN & ERNEST NAGEL, AN INTRODUCTION TO LOGIC AND SCIENTIFIC METHOD chs. 11-12 (1934); David Bohm, *On the Problem of Truth and Understanding in Science*, *in* THE CRITICAL APPROACH TO SCIENCE AND PHILOSOPHY ch. 14 (Mario Bunge ed., 1964); POPPER, *supra* note 40, at 37. *See generally* CRUMP, *supra* note 72, at 301-03 (relating observation, concept, and computation).

117. REESE, *supra* note 73, at 599-601; ALEXANDER KOLIN, PHYSICS: ITS LAWS, IDEAS AND METHODS 261, 295-98 (1950).

118. REESE, *supra* note 73, at 599-601.

119. REESE, *supra* note 73, at 599-601.

120. *See supra* note 116 and authorities therein cited.

121. *See supra* note 1 and accompanying text.

122. *See supra* notes 1-2 and accompanying text.

2. Science as Concept or Theory: The Rationalists

But others disagree with the empiricists, seeing the core of science as concept rather than observation.[123] A series of observations of a gas such as oxygen or ammonia would allow us to provide charts of the relationships among pressure, volume, and temperature, but if the strict empiricist is correct, we could not predict other data points. We could not even interpolate between observed data points, because this would require a concept or theory. Furthermore, unless linked by a concept, our measurements would remain as nothing more than raw data. Boyle's Law, by contrast, provides a model, or a concept, that organizes the data, even if it is imperfect.

Sir Isaac Newton, for example, was a rationalist rather than an empiricist.[124] He deduced numerous relationships in the physical world, producing what now is referred to as Newtonian mechanics, as a conceptual exercise, although subject to verification. While recognizing the need for revision if the concepts he postulated proved empirically wrong, he saw science largely as concept or logic, or as rational rather than purely empirical.[125] Newton's famous statement, "[h]ypotheses non fingo," or "I don't generate hypotheses," which is at the beginning of this Article,[126] clashes sharply with Popper's theory that science is hypotheses and testing. Newton did not generate hypotheses because he deduced his ideas conceptually.[127]

3. Science as Mathematical Relationship: The Quantitative Theorists

In addition to observation and concept, there is a third part of the puzzle—quantitative theory.[128] There are those who say that formal quantitative theory is the heart of science. You cannot understand a phenomenon, they insist, unless you can assign numbers to its inputs and derive numbers for its results.[129] Boyle's Law, for all its imperfections, fits this conception.

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123. *See generally* authorities cited *supra* note 116 (relating observation, concept, and theory). *See also* DONALD PALMER, DOES THE CENTER HOLD?: AN INTRODUCTION TO WESTERN PHILOSOPHY chs. 2-3 (2d ed. 1996) (explaining rationalist and empiricist epistemologies); GUNNAR SKIRBEKK & NILS GILJE, A HISTORY OF WESTERN THOUGHT FROM ANCIENT GREECE TO THE TWENTIETH CENTURY chs. 10, 12, 26 (7th ed. 2000) (same).

124. *See* CRUMP, *supra* note 72, at 303.

125. CRUMP, *supra* note 72, at 303.

126. *See supra* note 3 and authorities therein cited.

127. The story of the falling apple illustrates the manner in which Newton proceeded by thinking rather than experiment. *See supra* note 73.

128. *See, e.g.*, CRUMP, *supra* note 72, at 301-03.

129. CRUMP, *supra* note 72, at 301-03.

4. Science as Differing from *Daubert* in Requiring Accommodation of All Three Criteria: Observation, Concept, and Computation

The point is this: in some measure, science consists of all three of these factors. Few philosophers of science today would regard any of the three ingredients as irrelevant.[130] A concept that does not fit the facts at all is not useful, and neither is a jumble of raw empirical data correlated by no concept, however falsifiable they may be. Furthermore, neither a theory nor a set of numbers has any meaning unless to some extent it can be treated comparatively, which is to say quantitatively. The philosophers differ primarily in how they emphasize these ingredients.

And this, in turn, is the trouble with *Daubert-Kumho*. The cases do not express any recognition of the other two ingredients in the triad, concept and computation. Instead, they seem to make everything depend on falsifiability, which is to say, on observation.[131] By thus choosing to base its approach to science on a single short passage from a single philosopher, even one as prominent as Popper,[132] the Supreme Court in *Daubert* may have reduced the meaning of science to only a part of itself. In the next section of this Article, we shall examine the ironic result, which is that a straightforward application of the *Daubert* factors seems to label as unscientific many kinds of theories that seem to be valid and useful.

B. The Consequences of Using Falsifiability as the Test for Science: From Biological Taxonomy and Relativity Theory to Newton, Einstein, and Freud

Popper's theory of falsifiability, that experimental verification is the defining element of science,[133] would make some branches of what is thought of as science unscientific, if applied with rigorous logic. Consider the example of biological classification or taxonomy. It is difficult to "prove" observationally that a whale is a mammal, or that a spider is not an insect. We can "prove" these facts by resort to definitional characteristics, such as that mammals are warm-blooded and that insects have six legs, but this is merely a concept, not falsifiable in itself; it might be equally possible to construct a definition by which a whale is a fish.[134]

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130. CRUMP, *supra* note 72, at 301-03; *see also* KOLIN, *supra* note 117, at 5 ("[A]quisition of knowledge about nature is not accomplished by perception alone. It is achieved by a combination of perception and reasoning.").

131. *See supra* Part I.

132. *See supra* note 1 and authorities therein cited.

133. *See supra* note 1 and authorities therein cited.

134. *Cf.* MICHAEL RUSE, BUT IS IT SCIENCE?: THE PHILOSOPHICAL QUESTION ON

1. Does *Daubert* Disqualify the Biological Taxonomist?

The concept of a "mammal" or an "insect" is like all concepts: it is designed to show relationships, and the test of its validity, arguably, should be whether it is useful for that purpose,[135] not whether it is capable of experimental proof. As constructed in *Daubert*, Rule 702 admissibility depends on whether the expert's opinion could "assist" the jury, and the biological taxonomist's theory about mammals does seem to assist in understanding them. The utility of the concept is that we can predict other characteristics of whales and trace their evolution better by treating them as mammals.[136] Still, our classification of a whale as a mammal remains conceptual, and it is emphatically not experimentally verifiable. It is not possible to falsify the statement that a whale is "like" a horse, when the whale is like a horse in some respects and unlike it in others. A straightforward application of *Daubert*, therefore, seems to call for exclusion, even if the opinion might assist the jury.

Is the classificatory biologist, then, wrong in claiming to be a scientist? Or is Popper's theory wrong? And now, a key legal question: if an empiricist says the taxonomist isn't a "scientist," does this mean that the taxonomist cannot testify in court? Under the Supreme Court's reasoning in *Daubert*, perhaps it does!

In fact, this difficulty with Popper's philosophy is so well developed that it is hard to justify the Supreme Court's uncritical acceptance of its briefly stated doctrine of falsifiability. The difficulty is explained in college texts. For example:

> But what about the statement, "the average temperature on the surface of the earth when the human race is extinct, will be 70°C"? 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.[137]

THE CREATION/EVOLUTION CONTROVERSY ch. 16 (1988) (discussing this question).

135. *Cf.* 25 ENCYCLOPEDIA BRITTANICA, Philosophy of Science 667-76, Philosophy of Nature 678-92 (1989) (including the observation that while the British philosophy of science, exemplified by Popper, depends heavily on falsifiability, the American view instead has emphasized "what works").

136. *See generally* CARL JAY BAJEMA, NATURAL SELECTION THEORY: FROM THE SPECULATIONS OF THE GREEKS TO THE QUANTITATIVE MEASUREMENT OF THE BIOMETRICIANS (1983) (discussing the history of evolutionary theories).

137. SKIRBEKK & GILJE, *supra* note 123, at 429.

This shows that it is problematic to identify the distinction between statements that are falsifiable-in-principle and statements that are not falsifiable-in-principle with the distinction between science and non-science, and even that between cognitively meaningful and cognitively meaningless statements. Popper himself recognized this difficulty and compromised with rationalism. He even used the term "critical rationalism" to refer to his own position.[139] Deduced specific statements were not to be tested against reality.[140] This assumption legitimizes branches of knowledge such as logic, mathematics, or game theory that are not falsifiable as a matter of principle; without it, with only the falsifiability criterion, the credentials of a deductive expert in these fields would disappear. Popper saw science as dialectic, and he took a pragmatic approach: repeated experiences of many people can provide the needed objective foundation.[141] Furthermore, he pointed in a direction opposite from that of *Kumho* by maintaining that non-scientific disciplines (history was his example) could not be tested by the same criteria.[142] Later, other philosophers, for example, Thomas Kuhn, pointed out other arguable flaws in Popper's falsifiability theory.[143]

2. From Tachyons to the Laws of Mechanics: Could Rationalists Like Einstein or Newton Testify under *Daubert*?

Another test of Popper's philosophy is the relativity construct of tachyons. Nothing we know of can move faster than the speed of light, and relativity theory suggests that creating such a fast-moving object is impossible, because the energy required to accelerate it would exceed all of the energy that exists in the universe. This concept, however, has led relativity theorists to postulate the existence of "tachyons," which travel faster than light ("tachy" is taken from a Greek word meaning fast). Just as nothing else can exceed the speed of light, tachyons cannot slow down to light speed, because the energy they would give off would exceed what the universe could absorb.

Many of the predictions of relativity theory have been verified by observation, but we have never seen a tachyon. It is difficult to catch them. We may never observe them. Does this conclusion mean that theories contemplating

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139. *See* SKIRBEKK & GILJE, *supra* note 123, at 430-31.

140. *See* SKIRBEKK & GILJE, *supra* note 123, at 430-31.

141. *See* SKIRBEKK & GILJE, *supra* note 123, at 430-31.

142. *See* SKIRBEKK & GILJE, *supra* note 123, at 431-32; *see also* KARL RAIMUND POPPER, THE POVERTY OF HISTORICISM (1957).

143. *See* SKIRBEKK & GILJE, *supra* note 123, at 433-35. Kuhn's view included the insight that scientific truth is relative to the paradigm or model with which the theorist worked. A paradigm shift changed the reality and hence the falsifiability of statements made within the previous paradigm.

tachyons are unscientific, under Popper's theory? If so, were all of the predictions from relativity, including those that since have been experimentally observed,[144] "unscientific" when Albert Einstein first conceived them?

The point is a simple one: a narrowly insistent confinement of science to empiricism, such as the one that emerges from a literal reading of *Daubert*, would destroy a great deal of what seems to fit a fair definition of science. Newton's mechanics, including his equations that involve mass, velocity, and momentum, were conceived originally as a matter of logic or concept, and not by empirical observation.[145] Would a court, in Newton's time, have felt constrained to exclude the greatest scientist of all time from testifying, on the ground that his reasoning was conceptual? Perhaps tachyons make a more poignant example, because although they are derived directly from relativity theory, much of which has been empirically verified, no one is likely to be able to devise an experiment that will support or falsify their existence. Would a court of Einstein's day, therefore, be forced to exclude him from the courtroom, if it applied the *Daubert* criteria?

In response to this question, Professor Edward J. Imwinkelried has devised a wonderful hypothetical, with the suggestion that if the result is the exclusion of Einstein's testimony, that ruling is no disaster:

> I'm not troubled by precluding Einstein from testifying about tachyons. I'll grant you that last week on Star Trek—The Next Generation, Picard did use a network of tachyon beams to detect cloaked Romulan warships. However, that's in another century far in the future when they really have evidence that tachyons exist. If Einstein proposed testifying about tachyons today and another credentialed expert tried to link a tort defendant's industrial operations

144. *See* KOLIN, *supra* note 117, at 840-41 (describing the Michelson-Morley experiment); *id.* at 856-57 (describing experimental verifications). For technical accuracy, it is necessary to add that Popper's falsifiability criterion requires only falsifiability "in principle," not falsifiability with today's technology. In other words, science may include those statements, including assertions of the existence of tachyons, that we may some day be able to falsify with yet-nonexistent technology. *See* SKIRBEKK & GILJE, *supra* note 123, at 429. But for three reasons, this distinction does not seem to be a viable ingredient of the *Daubert* reasoning. First, it is unlikely that most judges would be able to apply it. *Cf.* Daubert v. Merrell Dow Pharm., Inc., 509 U.S. 579, 601 (1983) (Rehnquist, C.J., dissenting) (Chief Justice Rehnquist's confession that, "I am at a loss to know what is meant" by "falsifiability"). Second, it would produce the nonsensical result of legitimizing, as science, statements that we have no way of testing, precisely because we cannot test them but might some day be able to. Third, whether a statement is falsifiable "in principle" will frequently be a matter of debate. We may discover some day, for example, that tachyons are inherently uncertain and that there are principled reasons why we may never discover them.

145. *See supra* notes 124-27 and accompanying text.

> with tachyon interferences causing illnesses, I think that a judge would and should bar the testimony.[146]

I agree with this prediction. I wonder, however, whether it shows the range of possible uses of the testimony. The issue in the Imwinkelried conjecture arguably is the "fit" of the tachyon testimony, not its "reliability."[147] This is so because the cause for exclusion has to do not with whether tachyons exist but with whether they are known to cause disease (probably not). Thus, it is not Einstein's opinion about the existence of tachyons that besmirches this evidence, but rather the second (non-Einsteinian and unknown) witness' opinion that they are relevant to diseases. (This kind of confusion is endemic to *Daubert* hearings.)

I readily grant that it is difficult to come up with an example of a case in which the determinative issue is whether tachyons exist or not. When faced with this kind of difficulty, I usually resort to a hypothet about gamblers in Las Vegas. Two citizens of Nevada have entered into a million-dollar bet about whether tachyons exist. If they do, the first Nevadan owes the other the money; if they do not, then vice versa. At trial, the first Nevadan calls Albert Einstein as a witness. This great scientist's expert opinion (let us say) is that the question is a close call, but in all probability, from everything he has seen, tachyons do exist. If these are the claim and the evidence, I believe it is a bit narrow-minded to exclude the evidence on the ground that we cannot see tachyons and, therefore, may never be able to falsify them. And I would bet that a court in Nevada, where bets are a major item of commerce, would want to get to the truth.

Of course, these hypothets are wild. It is easy to say that neither one should be taken seriously. The difficulty, however, is that these imaginary cases are used here as examples that may be analogous to real and serious cases.[148] And then, the exclusion of scientific evidence because we cannot devise an experiment to detect the immediate subject matter although we can support it, at least, as a matter of "appropriate validation,"[149] is troubling.

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146. E-mail from Professor Edward J. Imwinkelried to Professor David Crump (Mar. 12, 2002, 9:39 a.m.) (copy on file with author).

147. The *Daubert* Court distinguished between the "validation" of a principle and its "fit" to the question at hand. A given principle may be perfectly valid but have nothing to do with the issue before the court. Thus, scientific testimony about phases of the moon may be valid, but although it may be used to demonstrate probable darkness on a particular night, it should not be used to demonstrate than an individual behaved irrationally on that night (the "werewolf" inference). *See Daubert*, 509 U.S. at 591. The same distinction applies to Professor Imwinkelried's example. The inference that tachyons exist may be valid, but it may not fit the question at issue because it is not demonstrably relevant to the etiology of diseases.

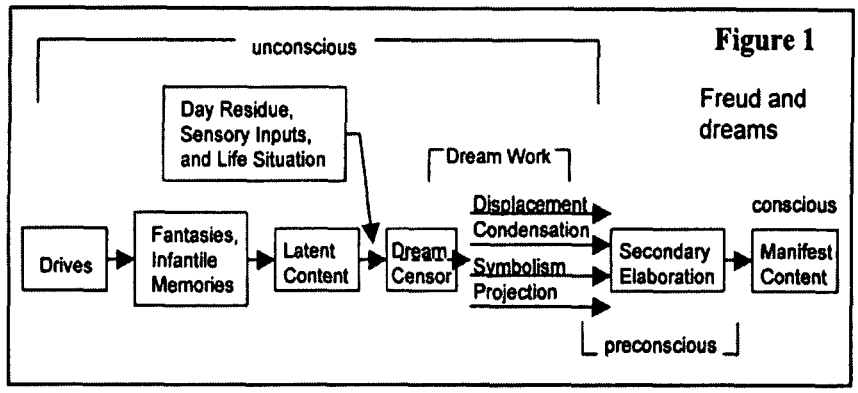
148. Such as *Daubert*, *Joiner*, and *Kumho*.

149. Again, appropriate validation should be the overall issue, not such subsidiary

3. Freud and Dreams: A *Daubert* Nightmare?

Then, there is Freud. If a case concerning nightmares had arisen during Freud's time, would the *Daubert* standard have permitted him to testify? Freud's seminal book, *The Interpretation of Dreams*,[150] characterized dreams as censored, symbolic stories that camouflaged their "latent content," which expressed unconscious drives that would be too frightening to confront if made explicit. Many contemporary psychologists have no use for Freud. His work did not pretend to be predictive, and, therefore, it was not uniformly replicable. But Freud and his followers created the framework of modern psychology by seeking to explain the irrational, the disordered, and the unconscious, and he probably could tell a jury more that might "assist" in understanding dreams, to use the terminology of Rule 702, than anything else available in his time.[151]

Freud's elaborate theory of dream process, which is diagramed in Figure 1,[152] did depend upon repeated empirical observations of patients in psychoanalysis, but not in a replicable way. It depended more heavily on Freud's non-replicable interpretation of those observations. Freud asserted that psychoanalysis could trace most dreams to sexual issues or, as he put it, to "erotic wishes." A knife, umbrella, or airplane in a dream, for example, might really symbolize a penis. A cave or bottle symbolized female genitalia.[153] It is difficult to conceive an experiment that would falsify these theories. Therefore, even though Freud might have had much to say that might assist a jury in his time, *Daubert* probably would not have permitted him to say it.



matters as the concept of falsifiability. *See supra* Part I.A.

150. SIGMUND FREUD, THE INTERPRETATION OF DREAMS (James Strachey ed., trans., Basic Books 1955).

151. *Cf.* CRUMP, *supra* note 72, at 351-54.

152. The diagram is taken from CRUMP, *supra* note 72, at 352.

153. *See generally* FREUD, *supra* note 150.

In fact, some of Freud's testable hypotheses have been rejected by observation. His idea that personality development was concentrated in childhood stages (particularly the "oral" and "anal" stages) is contradicted by research indicating, instead, that development is lifelong, and his assertion that gender identity emerges from an "Oedipal complex" (or a five- to six-year-old child's resolution of sexual attachments to the opposite-gendered parent) is contradicted by evidence that gender identity emerges much earlier, and emerges in households without opposite-gendered parents.[154] Yet many of Freud's groundbreaking ideas have survived. Above all, his insight into the irrational, the disordered, and the unconscious as means of explaining the human mind is both the framework of modern psychology and a principle that could be of great value to a jury charged with deciding an issue to which it might be relevant.[155]

Psychologist Richard Evans traces the history of psychology as beginning with models of the mind that were highly conceptual (Freud and his contemporaries) and progressing to behavioralism that was empirically replicable (such as B.F. Skinner's learning theory experiments). Although recognizing that this sequence is subject to exceptions, Evans notes that today, the pendulum seems to have swung back to include conceptual studies of the mind, which are not divorced from empirical support but depend much more on rationalist modeling.[156] The sequence is subject to exceptions, but Evans sees this mind-to-behavior-and-back-to-mind-again pattern as the thread of the history of psychology. Perhaps it is possible that the human mind requires us to adopt a lesser fidelity to empiricism than *Daubert* seems to demand, if we are to study all of it.

Again, I turn to the wisdom supplied by Professor Imwinkelried for reaction. Perhaps it is too pessimistic to expect that most judges would exclude Freud's testimony, or for that matter, Einstein's or Newton's. As Professor Imwinkelried puts it, "I certainly don't think that *Daubert* mandates [that] result."[157] And I agree—*Daubert* should not be read to mandate that result. Professor Imwinkelried suggests that the emphasis should be upon the Court's call for "appropriate validation." Following Professor Risinger, he would have the court focus specifically upon "the task at hand":

> The trial judge isn't supposed to make global judgments about either a discipline or all of an expert's theories. The only question is whether there is appropriate validation for the precise theory he or she contemplates testifying about. . . .

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154. *See* CRUMP, *supra* note 72, at 353.

155. *See* CRUMP, *supra* note 72, at 353.

156. *See* CRUMP, *supra* note 72, at 353.

157. E-mail from Professor Edward J. Imwinkelried to Professor David Crump (Mar. 12, 2002, 9:39 a.m.) (copy on file with author).

> [A]lthough you're probably right that *Daubert* places undue emphasis on empiricism, you need to give the opinion credit. I like the Court's reference to "appropriate validation." . . . [In certain kinds of cases involving testimony about Freud's theories,] proof that the theories are widely accepted and effective would arguably be "appropriate validation." Certainly, in mathematics, rigorous deduction is "appropriate validation."[158]

Again, I agree. And if Justice Blackmun's opinion had stopped after observing that appropriate validation should be required, the use of an "appropriate validation" test would be clearly indicated and possibly more workable than the current regime.

The trouble, however, is that Justice Blackmun translated this phrase, "appropriate validation," into his four suggested criteria of falsifiability, peer review, error rate, and general acceptance, with a "key" factor being testability or falsifiability.[159] And the further trouble is, even if Freud's dream theories can be propped up by the overall test of appropriate validation, the existence of the dream censor and the meaning of secondary elaboration are falsifiable only if one uses an artificially generous definition of that term. Furthermore, in *Kumho*, the Court held that a trial judge sometimes can look to an entire discipline to determine whether a specific opinion should be excluded.[160] Nevertheless, Professor Imwinkelried's suggestion may provide the solution to the problem. If courts were to emphasize the overall question of appropriate validation, rather than relying on strict falsifiability, the law of expert opinion might be more sensible. A trial court conscientiously applying the *Daubert* "factors" would not be drawn so easily into nonsensical results such as excluding fingerprint identifications[161] if it sought only "appropriate validation." But doesn't the actual contrary holding reached by one court show how, despite Professor Imwinkleried's hopeful predictions, *Daubert* and *Kumho* are signposts that direct judges frequently toward silly results? The problem here, I fear, is that the reverberating clang of the four factors, particularly the key factor of falsifiability, drowns everything else out. Fingerprint identification easily can be

158. *Id.*; *see generally* D. Michael Risinger, *Defining the "Task at Hand": Nonscientific Science After* Kumho Tire Co. v. Carmichael, 57 WASH. & LEE LAW REV. 767 (2000).

159. *See supra* Part I.A.

160. Kumho Tire Co. v. Carmichael, 526 U.S. 137, 153 (1999).

161. *See supra* notes 10-11 and accompanying text.

"appropriately validated"[162] even though questions about its falsifiability, peer review, and error rates produce a morass.[163]

4. Howard Gardner's Seven Intellectual Competencies: Excludable under *Daubert*?

Howard Gardner is a modern example of this mind-to-behavior-and-back-to-mind development. Contrary to the establishment view of educational psychology, Gardner rejects any general concept or measurement of intelligence. "I place no particular premium on the word intelligence," he explains, "but I do place great importance on . . . various human faculties."[164] Gardner identifies seven distinct "intellectual competencies": (1) linguistic, (2) musical, (3) logical-mathematical, (4) spatial, (5) bodily kinesthetic, (6) interpersonal intelligence (or personal intellectual competence in social interaction), and (7) intrapersonal intelligence (or competence with respect to one's own personality). His argument is that there is no one phenomenon of intelligence, although people differ in these seven competencies.[165]

Gardner does not defend his theory with quantitative data, or indeed with uniformly testable reasoning.[166] Critics point out, furthermore, that general intelligence testing shows a significant correlation with high competence in each of his seven models, suggesting that there is, in fact, a general intelligence concept that unifies all of Gardner's types.[167] Gardner responds by declining to accept the correlation, on the ground that current tests are biased.[168]

Does Gardner, then, have a point (and if so, should the law acknowledge it)? The idea of multiple intellectual competencies is intuitively appealing. Certainly, we all have known logical people with relatively little in the way of social skills, musicians who were not very logical, and linguistic people who were not good at introspection. Does common experience, then, provide an empirical basis for Professor Gardner's seven-part model, just as everyday

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162. For example, by reference to the authorities cited by the court in *United States v. Llera Plaza*, 188 F. Supp. 2d 549 (E.D. Pa. 2002).

163. *See supra* notes 10-11 and accompanying text.

164. HOWARD GARDNER, FRAMES OF MIND: THE THEORY OF MULTIPLE INTELLIGENCES x-xii, 17, 60-61, 278 (1983).

165. *See id.* at x-xii; 17, 60-61, 278; STEPHEN J. GOULD, THE MISMEASURE OF MAN 27-28 (1981) (asserting that "determinist arguments for ranking people according to a single scale of intelligence . . . have recorded little more than social prejudices").

166. *See* RICHARD J. HERRNESTEIN & CHARLES MURRAY, THE BELL CURVE 7, 151-52, 280-81, 290, 483-84, 625-30 (1994); JOSEPH D. MATARAZZO, WECHSLER'S MEASUREMENT AND APPRAISAL OF ADULT INTELLIGENCE (1972); *see also* CRUMP, *supra* note 72, at 374-77 (discussing these authorities and the meaning of intelligence).

167. *See* authorities cited *supra* note 166.

168. *See* authorities cited *supra* note 166.

experience supports the law of gravity? If so, the question remains whether everyday experience sufficiently refutes the concept of general intelligence so that the law should recognize the idea of modeling specific competencies, as an alternative.

The *Daubert* approach, rigorously applied, seems to signify that Gardner's opinions would have to be censored in a courtroom.[169] A rationalist might accept Gardner's "radical" (his word) description as scientific, but an empiricist would be less likely to.[170] And what would happen if Gardner were offered as a rebuttal expert, for the purpose of raising questions about mainstream theory? The Supreme Court has not recognized a difference in the standard for rebuttal witnesses,[171] and, therefore, the censorship of Gardner's opinions would seem to remain the rule. This is particularly an ironic result given the influence that Gardner has had upon the educational establishment and upon mainstream psychologists. Gardner might well be able to assist a jury, but *Daubert* seems to mean that it would never hear him.

III. THEORIES AND THEIR LIMITS: WHAT MAKES A GOOD SCIENTIFIC MODEL?

A. What Kind of Theory or Model (Does It Depend on the Use to Which the Concept Is to Be Put)?

Next, we shall compare *Daubert* not just to the concept of science generally, but to the acceptability of particular scientific theories. Much of science consists of deriving "models" from observations or experiments.[172] Boyle's Law, as we have seen, is a concept or model superimposed upon our observations of gases.[173] Likewise, the "meatball" vision of an atom, with spherical electrons orbiting a nucleus composed of bigger spheres that are protons and neutrons, is a model. It is useful in some ways, inaccurate in others.[174] Models help us, first, to

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169. *See supra* Part I.A.

170. *See supra* Part II.A.

171. On the contrary, *Kumho* says that the *Daubert* approach applies to all expert witnesses. *See supra* Part I.C.

172. "In his analysis of a real system, a physicist constructs a well-defined model of the system and addresses the model." ROBERT K. ADAIR, THE PHYSICS OF BASEBALL 1-2 (2d ed. 1994).

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

174. It also is known as the "Bohr model" model. *See* REESE, *supra* note 73, at 163. A slightly more sophisticated version, the plum pudding model, conceives of the electron as a charge mass or cloud. *Id.* at 763. A much more sophisticated model is furnished by quantum mechanics. *Id.* at ch. 27.

understand the phenomenon that they represent, and second, to predict its characteristics.[175]

1. Understanding Models and Their Limits

Thus, modeling is a basic scientific endeavor. A "map" is a symbolic drawing of the physical area it represents. The map is not the territory, however, and the model is not the physical reality.[176] Models are to physical reality as maps are to the earth. Good maps distort less than bad ones, but all maps (and all models) distort. For example, the standard Mercator projection map, showing the earth as a rectangle, enlarges Greenland because it is closer to the pole.[177] Other projections, keeping areas consistent in size, also are possible, but they chop the earth into pieces, and they distort shapes in other ways.

Likewise, a road map fails to capture the shape, size, and appearance of intersections, so that it is possible to read a map accurately and yet miss a connection. In the same way, the "meatball" atom, even as it helps us to see the nucleus in relation to electrons, is inferior to a model recognizing electrons in shells or layers, or better yet, in slurred clouds.[178] Furthermore, electrons sometimes form cloverleaf or airplane-propeller shapes, rather than spheres.

But then, there is the principle referred to as Occam's Razor: other things being equal, the model with the fewest number of arbitrary elements ordinarily is preferable.[179] The model must accurately reflect reality to a useful degree, and to the extent it does not, it becomes inappropriate for some situations. But of two models, one containing a large amount of complexity and another less, the simpler is preferable if it describes the territory equally well. This principle sometimes is referred to as "Occam's Razor,"[180] after the philosopher William of Occam.[181]

Then too, despite Occam's Razor, some phenomena require multiple models.[182] The map-of-the-earth problem mentioned above is an example. A serious geographer might want to keep several projections around for consultation in different situations. Newtonian mechanics, or the classical physics of motion in which matter and energy are conserved and $F = ma$ (force

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175. *See* ADAIR, *supra* note 172, at 2.

176. *See* ADAIR, *supra* note 172, at 2.

177. *See* RANDOM HOUSE WEBSTER'S COLLEGE DICTIONARY 828 (2d ed. 1995) (defining "Mercator projection").

178. *See supra* note 174 and accompanying text.

179. *See* CRUMP, *supra* note 72, at 307-12..

180. *See* THE CAMBRIDGE COMPANION TO OCKHAM ch. 5 (1999).

181. *See id.* at 5. *See generally* CRUMP, *supra* note 72, at 307, 311-12 (discussing the relationship of Occam's Razor to other criteria for scientific modeling).

182. *See* CRUMP, *supra* note 72, at 307-08.

equals mass times acceleration), works well in most earthly conditions but poorly in other conditions, e.g., extreme gravitational fields, in which effects predicted by the theory of relativity become significant.[183] In the latter situation, we need a different model.

In other words, models have limits, and understanding the limits is as important as understanding the model. At extreme pressures, Boyle's Law may cease to operate even as an approximation.[184] Likewise, at very high or at cold temperatures, the gas may undergo a phase change (oxygen becomes a liquid, for example).[185] One of the characteristics of models is that they cease to operate, even as analogies, beyond their limits of application. Perhaps a better way to put the matter is that models must be used within their constraints.

2. On the Usefulness of Bad Models: From Light Waves and Particles to Planetary Motion

This discussion brings up a related question: how bad can a model be, and still be useful? This is an issue that the Supreme Court's reasoning in *Daubert* and its progeny fails to address, and yet, as we shall see, it is a critical problem. Imagine that a concept gives valid results only part of the time. Is it useful, then? To take a specific example, we have two radically different concepts of light: the wave theory and the particle theory.[186] Wave theory is useful for some purposes, such as explaining color and interference.[187] But particle theory, which conceives of light as a stream of particles called "photons," is better for understanding other phenomena, such as the photoelectric effect.[188]

How can light be like a wave, like those that we see in the ocean, and a stream of particles like tiny baseballs, both at the same time? The answer is that it is not really "like" those things, and waves and particles are mere analogies. These physical comparisons are merely the best that human minds can do to understand this unique phenomenon called light. We probably will never see either a photon or a light wave, since the required resolution by definition makes it impractical to see them using light itself. But how do we know which model to use? Is the choice by which we decide which model to use really "scientific"? An answer to this question based upon the *Daubert* reasoning would respond

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183. *See* CRUMP, *supra* note 72, at 307-08.

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

185. *See* REESE, *supra* note 73, at 602-04.

186. "[E]lectrons too [or light] could not be regarded simply as corpuscles, . . . periodicity [i.e., frequency, as with waves] must be assigned to them also." LOUIS DE BROGLIE, MATTER AND LIGHT: THE NEW PHYSICS 169 (W.H. Johnston trans., 1939) (1937); REESE, *supra* note 73, at 1235-39.

187. REESE, *supra* note 73, at 1053-54, 1104-05.

188. REESE, *supra* note 73, at 6, 1211-16.

that it is not scientific, because it is driven by what works rather than by what is falsifiable. We cannot prove or disprove that light is "like" waves or particles, because it is like (and unlike) both. The *Daubert* approach, literally applied, would exclude such a theory, even though it can be useful.

Another example, from the opposite end of the scale, is raised by the mechanics of planetary motion, or rather by the history of our understanding of it. In the second century A.D., the Alexandrian astronomer Ptolemy publicized a concept of the universe with a fixed earth at its center and the sun, moon, planets, and stars rotating about it.[189] Was this model "scientific"? The answer, entirely plausibly, is yes, at least in terms of the *Daubert* decision, in that a great deal of observation could be offered to support it, and no one knew how to falsify it at the time.

In later years, the earth-centered model was refined. The heavenly bodies all were embedded in concentric balls of crystal, to reflect their different distances from the earth. Their rotation (believe it or not) was thought to produce "the music of the spheres."[190]

For a long time after that, politically correct scientists postulated "epicyclic" orbits for the planets.[191] These were necessary because observation showed that planets sometimes backtracked in the sky.[192] An epicycle is the shape traced by a point on a circle that rolls about the circumference of another circle, and it explained the so-called "retrogression" of the planets.[193] But again, the theory failed to account for observations, leading scientists to construct epicycles within epicycles. One factor driving this conceptualization was the Church, which preferred the existing earth-centered model over the sun-centered Copernican model to such an extent that it punished heretics, including Galileo, for efforts to challenge it. Epicycles fit the data better and, under the reasoning of *Daubert*, might appear more "scientific" than the Ptolemaic model.[194]

Finally, Copernicus's model won out, featuring a solar system that had the sun at its center.[195] But some scientists still erred in seeing planetary orbits as circular, whereas today we know them to be elliptical.[196] Was the basic Copernican model, then, unscientific? And, of course, Copernicus failed to adjust orbits for such phenomena as gravitational influences of close-passing

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189. REESE, *supra* note 73, at 4, 1042.

190. *See* CRUMP, *supra* note 72, at 309-10.

191. *See* COLIN RONAN, THE ASTRONOMERS chs. 4, 5 (1964); CRUMP, *supra* note 72, at 309-10.

192. *See* authorities cited *supra* note 73.

193. *See* RANDOM HOUSE WEBSTER'S COLLEGE DICTIONARY 443.

194. *See* authorities cited *supra* note 73.

195. *See* REESE, *supra* note 73, at 3-4.

196. *See* REESE, *supra* note 73, at 3-4.

bodies or solar wind. Perhaps the lack of an accounting for such future knowledge makes even our current views unscientific in *Daubert* terms!

And we can take this history one step farther by hypothesizing a revision of the earth-centered Ptolemaic universe. With more complex mathematics, we could ensure that an earth-centered model accurately conformed to planetary motions.[197] After all, the Ptolemaists were justified in the sense that all motion is relative.[198] It makes as much sense from the standpoint of mechanics to regard the sun as moving with respect to the earth as to regard the earth moving with respect to the sun. It also makes for more complicated calculations to describe the "motion" of the sun "around" the earth, but theoretically, it could be done.[199] And if that could be done, theoretically, we could describe the motions of the planets "around" the earth, with still more complex mathematics.

If our principal or exclusive criterion is falsifiability, as *Daubert* suggests,[200] this odd, complicated view of the solar system—the "Advanced Ptolemaic" theory—would be a good scientific model. This result follows from the relatively confined approach that the Supreme Court adopted toward science. A related problem is that the *Daubert* approach might exclude good models, as we shall see in the next section of this Article.

B. A Six-Part Method for Detecting a Good Scientific Model

1. Tractability, Simplicity, and Validity: Factors for Evaluating Models

One well-known conception describes three characteristics of a good scientific model: tractability, simplicity, and empirical validity.[201] The first factor, "tractability," means the amenability of the model to coherent treatment, or its workability. A jumble of uncorrelated experimental results might be empirically accurate, but it would not provide a good model because it would not be tractable. The second factor, "simplicity," is the concept described as Occam's Razor, *supra*. Finally, "validity" means correspondence to empirical observation, the principal criterion featured in the *Daubert* test.

This multi-factor theory avoids the trap of exclusive reliance on the views of either the rationalists or the empiricists. It recognizes that a model may be bad because it badly fits the empirical data. But it also recognizes that a model may be bad even though it mirrors reality perfectly, if it is not tractable—particularly

197. *See* CRUMP, *supra* note 72, at 309-10.

198. *Cf.* REESE, *supra* note 73, at 129-33 (explaining relative velocity addition).

199. *See* REESE, *supra* note 73.

200. *See supra* Part I.A.

201. *See* CRUMP, *supra* note 72, at 311-12 (explaining these criteria and refining them).

if there is a more workable model that entails only an insignificant loss in validity.[202] This theory, unlike the *Daubert* approach, enables us to discard the "Advanced Ptolemaic" model described above—the clumsy approach of assuming an earth-centered universe, and then sending the sun and planets in orbit around it by the use of complex mathematics.

In fact, there have been many approaches to this question. The great philosopher of science Charles Sanders Peirce, like the Supreme Court, reduced science to a matter of empiricism. Peirce's view is summarily described by Nicholas Rescher as follows:

> For Peirce, the only true test of the correctness of a theory is whether the interferences, applications, and predictions based on it prove successful. Purely intellectual factors such as explanatory power, parsimony, intuitive appeal, antecedent probability resulting from concordance with previously accepted theories, etc., are, for him, considerations relevant to the abductive process of selecting theories and hypotheses for testing. But these purely intellectual factors have no place in the specifically retroductive process of verifying the truth of theories and assessing their acceptability.[203]

On the other hand, physicist Steven Hawking posits what he calls a two-part theory (although it actually contains more than two ingredients): "A theory is a good theory if it satisfies two requirements: it must accurately describe a large class of observations on the basis of a model that contains only a few arbitrary elements, and it must make definite predictions about the results of future observations."[204] Actually, Hawking's two-part test fits comfortably with the three-part test described earlier. Hawking says that a theory must make "definite predictions about the results of future observations," or in other words, it must be (1) *tractable*. It must contain "only a few arbitrary elements," and, thus, it must be (2) *simple*. And finally, it must "accurately describe a large class of observations," meaning that it must be (3) empirically *valid*.

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202. *See infra* Part III.B.2.

203. NICHOLAS RESCHER, PEIRCE'S PHILOSOPHY OF SCIENCE: CRITICAL STUDIES IN HIS THEORY OF INDUCTION AND SCIENTIFIC METHOD 11 (1978).

204. Dan Hunter, *No Wilderness of Single Instances: Inductive Inference in the Law*, 48 J. LEGAL. EDUC. 365, 372 (1998) (quoting STEPHEN HAWKING, A BRIEF HISTORY OF TIME: FROM THE BIG BANG TO BLACK HOLES 9 (1988)).

2. Toward a General Theory of Scientific Models: A Six-Factor Approach to Compare to the *Daubert* Factors

Elsewhere, in another work, I have described a more detailed theory of scientific modeling, featuring a six-factor approach.[205] The six factors are refinements of the original three factors of tractability, simplicity, and empirical validity. First, I believe that tractability consists of at least two factors: (1) *communicational* tractability, or how well the model can be used to convey ideas from one person to another, and (2) *computational* tractability, or the amenability of the model to mathematical calculations.[206] Then, simplicity also involves at least two factors: (3) *Occam's Razor*, or the preference for the fewest number of arbitrary elements, and (4) *generality*, or the propensity of the model to organize larger rather than smaller amounts of data (this ingredient also appears in Hawking's statement).[207] Finally, validity consists of at least two elements: (5) close correspondence to *empirical observation* within the range of the model's correct application, and (6) clear *demarcation* of its limits or constraints.[208]

In summary, a scientific model is good if: (1) it is readily communicable, (2) suitable for calculations, (3) based on relatively few elements, (4) generally applicable, (5) consistent with observed data, and (6) subject to a clearly defined range of application. It is a poor model if it is: (1) difficult to communicate, (2) hard to use for a calculation, (3) bristling with arbitrary elements, (4) narrowly applicable, (5) crude in accuracy, and (6) unclear in the limits of its applicability. Let us, now, illustrate each of these six factors with examples. We shall also compare the factors with the *Daubert* approach.

a. Communicability: A Factor Omitted from the *Daubert* Approach

The first factor is communicability, or usefulness in conveying the idea to an uninitiated person. Because this concept bears a close resemblance to the "assist" standard in Rule 702, one might suppose that the *Daubert* approach would emphasize it, but as we shall see, *Daubert* seems to omit this factor.

As an example of the communicability criterion, let us consider models of the particles in an atom. Models range from the crude but familiar to the sophisticated but fearsomely mathematical.[209] Quantum physics, such as the forest of squiggles known as the Schroedinger Wave Equation, provides a more accurate description of the behavior of electrons than does the simplistic ball-

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205. CRUMP, *supra* note 72, at 311-14.
206. CRUMP, *supra* note 72, at 311-14.
207. CRUMP, *supra* note 72, at 311-14.
208. CRUMP, *supra* note 72, at 311-14.
209. *See supra* note 210.

and-stick or "meatball" model of an atom.[210] Nevertheless, the meatball model may be superior for some applications. If we are trying to communicate with average jurors about the relative functions of electrons, protons, and neutrons in a prototypical element, and if the context of the problem does not require attention to quantum effects, the meatball model will be decidedly better for communicating what is meaningful. In this usage, it is a better scientific model.[211]

One problem with the *Daubert* formulation is that it does not recognize this factor at all. It does not recognize the tradeoff between communicational tractability and empirical validity. The meatball model is inaccurate, and that is the touchstone of the *Daubert* approach. The possibility that a negligible sacrifice in empirical validity (with respect to an irrelevant matter) might lead to significantly more meaningful and valuable communication is not expressly a part of the *Daubert* calculus.

b. Calculability: Also Omitted under *Daubert*

Next, we consider the second factor, calculational tractability (or "calculability"). Let us use the everyday example of finding the circumference of a circle, using the formula $C = 2\pi r$. Pi (π) is an irrational number, and, therefore, all we can do in the real number system is to approximate or model it. For some uses, we might need a precisely defined model of π, with many decimal places, such as 3.14159 . . . , although even if we were to calculate it out to a hundred decimal places, any real number we might produce still would be provably wrong.[212] For many uses, it is customary to model π by using the simple fraction, twenty-two sevenths (22/7), which is close to 3.14159 but less exact, because it is simpler to use in calculations.[213] In short, 22/7 might

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210. The Schroedinger Wave Equation computes energy levels in Electron Shells. Are you ready?

$$H\psi = -i\hbar\frac{\partial\psi}{\partial t} = \frac{-\hbar^2}{2m}\nabla^2\psi + V(0, X)\psi$$

This model uses what my old Physical Chemistry text calls "familiar mathematics"(!) although it also says that this "simplified equation" is "such a bad approximation that it is no value." For an approach accessible to students of college physics, *see* REESE, *supra* note 73, 1260, 1263-64.

211. *See* CRUMP, *supra* note 72, at 312-14.

212. *See* RANDOM HOUSE WEBSTER'S COLLEGE DICTIONARY 997 (1995).

213. Specifically, 22/7 = 3.1429, which differs from π by a figure that cannot be specified but slightly exceeds 0.0005.

sometimes be a better model for π than the more accurate 3.14159. It is more computationally tractable (or more calculable).[214]

Let us imagine a *Daubert* hearing in which a scientist has used the 22/7 model, and the opposing lawyer desires to exclude the expert's opinion. Perhaps the problem is one for which 22/7 is a serviceable estimate of π (for example, let us assume that π is used in this case to estimate the number of plants necessary to border a circular flower bed). The examination of the witness proceeds somewhat as follows:

> Q.: Now, Doctor, when you used 22/7 as a substitute for pi, you knew it wasn't accurate, didn't you?
> A.: Well . . . , yes. It's not "accurate."
> Q.: Well, can you tell us what would be an accurate number for pi?
> A.: No. You see, there isn't an exactly accurate number for pi in our decimal system. It's an irrational number.
> The judge (turning pale): What? Irrational?
> A.: Yes. Irrational.
> (The judge shakes his head.)
> Q.: Okay, Doctor. Now, let's talk a little bit about the peer review issue, because Justice Blackmun suggested in *Daubert* that we ought to talk peer review. The fact that 22/7 is not an accurate value for pi has been peer reviewed, hasn't it? What I mean by that, is: every mathematician would recognize that pi is an irrational number and that 22/7ths doesn't really fit it, isn't that right?
> A.: Yes.
> (The judge shakes his head.)
> Q.: And what about the rate of error, Doctor? I'll bet you're going to tell me that yes, there's an error in 22/7, but you can't tell us how big it is.
> A.: [brightening]: Exactly! Because pi is an irrational number, there's no way to tell exactly how inaccurate any particular estimator might be.

A prudent opposing attorney in this situation would refrain from asking about general acceptance, because any mathematician would recognize 22/7 as a serviceable approximation for π in appropriate uses. The trouble is, *Daubert* requires a complex, treacherous inquiry to figure this out. There can be no assurance, indeed, that a conscientious *Daubert* inquiry conducted by a judge

214. *See* CRUMP, *supra* note 72, at 312-14.

who did not understand π to begin with would ever figure it out, because computational tractability is not a part of the *Daubert* calculus.

Perhaps this appears to be an excessively pessimistic treatment of the *Daubert* factors. That appearance, however, results from the simplicity of the example, which is kept simple for reasons of clarity. Only a judge who has slept through an entire secondary education and who never learned about π could accept the argument for exclusion in this case. The problem, however, is that the scientific principles at issue may be more complex than this example, and less familiar to the judge. The point, again, is that no model is ever perfectly empirically valid,[215] and a negligible sacrifice in empirical validity may help us to choose a better model if we focus upon computational tractability.[216] But this issue is not a feature of the *Daubert* factors, and given that the existing factors emphasize issues unrelated to computational tractability, it may be impossible as a practical matter to get it across to a non-scientist judge.

c. Simplicity: The Third Factor, Also Absent from *Daubert*

The third factor is simplicity. Consider again the comparison between the Ptolemaic solar system and the Copernican one.[217] As we have seen, it might be possible to develop a series of equations that accurately would describe the solar system using the Ptolemaic model, i.e., with the sun circling the earth.[218] From the point of view of pure empirical validity, this model might be made to work as accurately as the Copernican model, provided that the equations we use are sophisticated enough to describe actual celestial motions. This "Advanced Ptolemaic" model would be inferior to the Copernican theory, or at least most approaches to science would so label it, and the main reason is simplicity.[219] The "Advanced Ptolemaic" system requires more arbitrary elements than the straightforward Copernican model.

The *Daubert* formulation, however, does not recognize this simplicity factor. This is an arguable shortcoming of the scientific philosophy that the Supreme Court has adopted.

d. Generality: The Fourth Factor, Also Omitted from the *Daubert* Criteria

The fourth factor is generality: the suitability of the model to describe a range of data, not just an idiosyncratic event. Let us resort once again to

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215. *See supra* Part II.A.1.
216. *See* CRUMP, *supra* note 72, at 312-14.
217. *See supra* Part III.A.2.
218. *See supra* Part III.A.2.
219. *See supra* Part III.A.2.

considering the "Advanced Ptolemaic" model.[220] Even assuming we could develop an accurate description of how known, existing solar system bodies move by sophisticated equations built on the Ptolemaic theory, this model might function poorly in describing other phenomena, such as the motion of a newly discovered comet. Moreover, it would require new empiricism before we could predict how a comet might behave in the vicinity of Alpha Centauri. Such a model would fail Hawking's requirement that it "describe a large class of observations,"[221] and in my six-part system, it would be inferior because it lacks generality.

The *Daubert* factors do not include this generality issue. Again, this is an arguable shortcoming in the Supreme Court's scientific philosophy.

e. Validity: The Linchpin of the *Daubert* Philosophy

Then, there is the issue of empirical validity. Consider Newton's physics, as compared to relativity theory. For some usages, Newtonian mechanics, in which $F = ma$ (force equals mass times acceleration),[222] and in which energy is conserved within closed systems,[223] may be highly accurate. But Newtonian mechanics are a poor model when relativistic effects are significant, such as in the space that is very close to a black hole.[224] The *Daubert* validity factors do not consider this issue, although a separate construct within the *Daubert* approach does deal with it. *Daubert* requires not only a principle that is valid, but one that "fits" the problem.[225] We might conclude that, when the issue concerns mechanics in the vicinity of a black hole, the Newtonian model does not fit.

Thus, the *Daubert* approach points to the answer in this case. This, however, is the only one of the proposed six tests of a good theory that is covered by *Daubert.*

f. Demarcation: The Final Factor, Omitted from the *Daubert* Approach

Then, finally, there is the issue of demarcation. Every theory has limits, and the theory may be better or worse because of our ability to tell where the limits are. A theory with defined, recognizable limits is better demarcated than one that requires us to guess whether it is applicable. Let us use the example of biological taxonomy, which may be a valuable science, but which produces

220. *See supra* Part III.A.2.
221. *See supra* note 204 and accompanying text.
222. REESE, *supra* note 73, at 176.
223. REESE, *supra* note 73, at ch. 13.
224. REESE, *supra* note 73, at 349-50.
225. *See supra* Part I.A.

difficulties with respect to demarcation.[226] The taxonomy of classifying a whale as a mammal along with a horse is valid in some respects, in that it allows us to infer that the two are alike: they are warm-blooded, hairy, and viviparous.[227] Beyond the definitional characteristics, however, the mammal model does not tell us very precisely which other characteristics may or may not be similar: the whale's size and ability to remain underwater, the horse's hoofs, mane, and running ability. We cannot really know whether any given prediction we make about the whale, based upon the horse, is going to prove true.[228]

This imprecision in demarcation might be a defect in the "mammal" model for some purposes, and the *Daubert* factors do not direct us to it. Again, this omission is a criticism of the scientific philosophy adopted in *Daubert*.

C. *Consequences of the* Daubert *Treatment of Scientific Models*

To the extent that this six-factor test of scientific models is meaningful, the *Daubert* factors create a dubious philosophy. The only factor for which *Daubert* points a signpost in the correct direction is that of validity. But communicability, calculability, simplicity, generality, and demarcation also are factors by which many scientific theories appropriately can be judged. Indeed, these other factors seem particularly important in the context of a trial before a jury. In this context, communicability is a major component of the assistance the theory can provide to the jury. Generality helps to avoid the application of a theory beyond its limits, and demarcation helps a jury to understand when the theory applies.

Some of these factors can be accessed through the *Daubert* factors, but the derivation is indirect. For example, tractability and simplicity may lead to general acceptance of a theory that is slightly less empirically valid, at least for some uses.[229] Thus, the general acceptance factor may be a way to read factors into the *Daubert* criteria that do not depend purely on empirical validity.[230] In some kinds of cases, perhaps peer review and error rates might do the same.[231] The problem, however, is that the *Daubert* listing of the four validity-related factors does not focus the inquiry accurately. More importantly, the Supreme Court's exclusive concentration on the question of empirical observation as the

226. *See supra* Part II.B.

227. *See supra* Part II.B.

228. *See supra* Part II.B.

229. *See supra* Part III.B.1.

230. *See supra* Part I.A.

231. *See supra* Part I.A. Peer review may discuss tractability and simplicity, and if the increase in rate of error is known to be small from a shift to a more tractable or simple model, that factor may be helpful too.

sole criterion of proper science[232] tends to make other factors seem out of bounds, even if they also furnish important tests of a scientific model.

IV. CONCLUSION: WHAT CAN BE DONE ABOUT IT?

The shortcomings of the *Daubert* approach could have been avoided if the Court had refrained from issuing detailed dicta, in the form of its four recognized validity factors, when it had acquired no experience in the subject. Chief Justice Rehnquist's partial dissent, in which he advised against these premature statements, pointed toward a wiser course, and the Court should have heeded it.[233] The Court may have believed that it was articulating a flexible[234] doctrine, in light of its provision for the addition of other criteria. But as often happens, a premature pronouncement that was intended to be flexible has become an established set of criteria.[235] It was foolhardy for the Court to ignore what was going to happen, which was that trial judges would consider the four *Daubert* factors to be legal principles established by the Supreme Court.[236]

Again, Professor Imwinkelried has wise counsel to the opposite effect:

> I seriously doubt that we would better off if Blackmun had ruled only that Rule 402 superseded *Frye*. At least the Court had the benefit of tens of amicus briefs, including many by scientific organizations. If Blackmun had not made any attempt to fill the void left by overruling *Frye*, I suspect that we'd have even more confusion among the lower courts. Based on my conversations with judges, I have the impression that the typical jurist in the trenches appreciated the guidance in *Daubert* and laments the lack of guidance in *Kumho*.[237]

Guidance to the lower courts obviously is an important attribute in a Supreme Court opinion. The guidance is less useful, however, if it is ill fitting or wrong, and that result becomes more likely when the Court does not know the territory. It is a balancing act. If it issues opaque opinions, the Court cannot expect uniform obedience, but on the other hand, if it offers general observations

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232. *See supra* Part I.A.

233. *See supra* Part I.A.

234. The Court said that flexibility was its goal. *See supra* Part I.A.

235. In fact, the Court reproduced and emphasized the four factors in *Kumho*. *See supra* note 97 and accompanying text.

236. *See supra* notes 10-11 and accompanying text (describing the *Plaza* case, in which a district court applied the "*Daubert* factors" to reach the outlandish result of uniformly excluding fingerprint identification).

237. E-mail from Professor Edward J. Imwinkelried to Professor David Crump (Mar. 12, 2002, 9:39 a.m.) (copy on file with author).

prematurely, it can expect the law to fall into a morass unless it has accurately guessed the shape of things to come. Worse yet, it may set the law in concrete and confuse issues yet to be confronted, as happened when *Daubert* led to *Kumho*. I believe the Court's call for appropriate validation[238] was useful and well-targeted, and that should have been all that the Court said, even though it may not have settled everything in one opinion. Likewise, I believe the four criteria in the Court's general observations went too far for a Court that found itself in uncharted territory.

In *Kumho*, the Court left the law in an even more unnecessary state of dysfunction. The Court recognized that non-scientific expert evidence was different from scientific evidence in ways that would vary from case to case, but then directed the lower courts to apply the scientific criteria to the extent they might prove useful.[239] The result is analogous to telling a person unfamiliar with both that a television set differs from an orange, but that unpredictable characteristics of one can appropriately be used in treating the other. The hypothetical listener should be forgiven if she attempts to eat the television set and watch the orange. That is what has happened in the cases that have followed *Kumho*. The result is decisions labeling fingerprint identification inadmissible and, for that matter, the result reached in *Kumho* itself.

The *Daubert-Kumho* line of cases is, however, the law of the land. This reality limits the practical issues. The question is, what can be done to make the most of it? The brightest prospect would be for the Supreme Court to overrule *Daubert-Kumho* and return to the "helpfulness" or "assist" standard that is embodied in Rule 702. Judges then could see expert opinion as primarily a relevance-based problem. Highly inaccurate expert evidence deserves to be excluded not because of something that Karl Popper said, but because it lacks sufficient probative value, compared to its tendencies to prejudice, confuse, and mislead, so that it fails the balancing test of Rule 403, as well as the assistance standard of Rule 702. One advantage of this approach is that it would allow admissibility decisions to be made under the standard of Rule 104(b). The question before the judge would be, "could a reasonable juror find this evidence to be helpful?," and it would not place the judge in the position of determining the validity of the scientific theory as a kind of amateur scientist. This difference, in turn, would mean that the *Daubert* hearings that so clog the trial courts today, and that so confuse the admissibility question, would become shorter and more focused. Junk science still could be excluded as not providing assistance, and as the Court pointed out in *Daubert*, the mechanisms of summary judgment or judgment as a matter of law provide additional ways to reach the same result.

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238. *See supra* Part I.A.

239. *See supra* Part I.C.

Unfortunately, abandonment of *Daubert-Kumho* also is unlikely. Nevertheless a trial judge can improve the administration of expert opinion decisions by recalling that the *Daubert* decision was premised upon the liberal admissibility policy embodied in the federal rules. The overarching question remains whether the opinion will "assist" jurors to understand the evidence or to determine facts in issue. The Court captured this idea, as Professor Imwinkelried suggests, when it required "appropriate validation."[240] It is this concept, not the four subsidiary *Daubert* "factors," that controls. The factors are means to an end (the end being a showing of appropriate validation, or of sufficient reliability to assist the jury), not specific requirements to be strictly applied. This consideration, together with the flexibility[241] that the *Daubert* opinion emphasizes, should enable the judge to consider communicability, calculability, generality, and demarcation[242]—the criteria for evaluating a scientific theory that do not deal exclusively with empirical validity—so that the result will be the assistance to the jury that Rule 702 requires of expert testimony.

240. *See supra* notes 157-58 and accompanying text.

241. *See supra* note 42 and accompanying text.

242. *See supra* Part III.B.2.