THE PATH MOST TRAVELED

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HAVING DISCUSSED BOTH THE *OBJECT* AND THE *domain* of the natural sciences, we now move on to consider the path followed by the scientific community as it seeks to achieve one of its principal *goals.* The scientific enterprise has many goals: to provide the means for controlling our environment; to provide the foundation for technology; to ensure our comfort, health and safety; and many others. Our present concern, however, is with natural science's goal of obtaining knowledge—sometimes referred to as its *epistemic* goal—its effort to gain knowledge about the physical properties, behavior and formative history of the world in which we live.

The principal forms of this knowledge are the results of empirical investigation and the products of scientific theorizing about the composition, structure, behavior and history of the physical systems that we observe. The empirical and theoretical components of this knowledge are closely interrelated and equally important. For this reason science education seeks both to train students to perform competent empirical investigation and to familiarize students with the array of scientific theories that contribute to the contemporary picture of the physical universe.

In this chapter we focus our attention on the system of *values* that functions in the process of scientific theorizing. While students of the natural sciences spend large amounts of time learning the *content* of numerous theories, and the developers of modern technology expend the majority of their effort in the creative and effective *application* of such theories, professional natural scientists direct their primary efforts toward the construction and *evaluation* of theories about physical phenomena.

Judging the merits of a particular scientific theory or choosing one theory from a set of competing theories concerning the same phenomena is a common activity within the scientific community. But on what basis are such judgments and choices made?

A half century ago it was commonly supposed that there existed some set of self-evident and rigidly applicable rules by which the truth or falsehood of a particular theory could be established once and for all. During the past few decades, however, historians and philosophers of science have developed a more realistic assessment of the way in which the scientific community functions.

It is now generally agreed that scientific theorizing is very little like the positivist* picture of the mechanical application of rigid logical *rules,* but is rather a *value*-guided activity of human judgment applied to the products of creative insight. Scientific theories cannot be constructed by a robotic assembly line, nor can theory evaluation be adequately performed by a roomful of even the most powerful of today's electronic computers.

If we wish to understand the process of scientific theory evaluation, we must see it as a wholly human enterprise. It is an activity performed by a community of persons—persons with finite knowledge, skills and insights—who must continually make judgments concerning the adequacy of scientific theories to account for the results of empirical investigation. Judgments must, of necessity, be based on accepted standards or values. On this system of values that the professional scientific community uses to evaluate theories we now focus our attention.

There exists no authoritative document which spells out the rules for scientific investigation, not even for the more restricted activity of theory evaluation. In the absence of such a canonical source the best we can do is to appeal to scientific practice itself in order to determine what general principles or value systems appear to operate. What follows, therefore, is a summary of insights into the historical practice of natural science provided by several observers of the scientific enterprise.[1] The list is by no means exhaustive. We shall limit ourselves to brief discussions of four categories of values—four categories of functioning criteria for judging the quality of scientific research or the adequacy of a scientific theory.[2]

Matters of Competence

Scientific research and theorizing is composed of a rich diversity of actions performed by scientists. For example, a long-range research program is planned, motivated by factors as varied as the colors in a rainbow; a specific question is posed for investigation; the investigators thoroughly familiarize themselves with the relevant literature; an empirical strategy is formulated; apparatus is selected or designed and assembled; the physical system or sample of material to be investigated is prepared; arrangements are made to control the environmental

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**Positivism* is a philosophical perspective that rests on the assertion that authentic knowledge can be obtained only from "positive," that is, scientifically verifiable, information.

conditions; the measurement system is calibrated against an accepted standard; the degree of uncertainty in measured values is assessed; the observations or measurements of interest are performed and the relevant data are recorded; measurements may be repeated; the data are analyzed; the results are organized for presentation in the form of verbal descriptions, tables of numerical values, graphs, algebraic relationships, or the like; the results may be compared with predictions or expectations; inferences concerning relevant theories are drawn, or a new theory may be proposed to account for the empirical results; suggestions for further related research are offered, leading, perhaps, to a similar cycle of empirical and theoretical activity.

As a general rule, every one of these activities constituting scientific research requires a certain degree of familiarity with procedure and skill in performance. To be a good natural scientist, one *must* acquire the knowledge and the skills that are needed to perform these empirical, analytical and theoretical operations with competence. Such craft competence is highly valued within the professional scientific community. The tradition of high expectations for competent performance is passed on from one generation of scientists to the next. Incompetent work is universally rejected.

But surely this demand for competence comes as no surprise. The primary goal of natural science is authentic knowledge concerning the character of the physical universe. The only paths leading toward that goal are those paved with the results of competent performance of the empirical and theoretical crafts; good intentions are not enough. Incompetent performance in scientific investigation is the pavement of a one-way path to misperception, delusion and false conclusions—no friends of knowledge. But, of course, incompetent performance is unwelcomed in any field of endeavor.

Matters of Integrity

Scientific investigation is performed by a community of persons who, of necessity, must depend on the professional integrity of the other members of that community. While research performed by one person or group may, for a variety of substantial reasons, be challenged and repeated by another, more commonly research reports are trusted to represent the results of competent work honestly reported. The *significance* of the report is open to question; the *convincing power* of its argumentation is subject to critical evaluation; but its *integrity* is expected to meet the unwritten, but nonetheless functional, code of professional ethics. Without a functioning set of ethical principles for integrity, the professional scientific community could not perform in the manner it presently does.

The fundamental principles are honesty, fairness and candor. Unquestionably, the willful propagation of reports that are known to be false or unreliable is totally unacceptable. And when observations or measurements are reported, we expect not only that the report provides an honest account of the results, but also that all reasonable precautions have been taken to ensure that these empirical results are reliable within limits that have been realistically assessed and candidly stated. If in the course of a computation one needs to use data obtained by other researchers, it is expected that the literature has been thoroughly searched in order to obtain the most reliable data available, often the data most recently reported. Unreliable, outdated or discredited reports should never knowingly be employed in support of one's case. Professional scientists are expected to exercise whatever level of diligence and self-discipline is required to minimize the propagation of false or misleading reports.

The process of extrapolation deserves special attention in the context of this discussion of professional integrity. Ordinarily the data base for the description of some behavior pattern is confined to a restricted range of circumstances. Any extrapolation of behavior patterns beyond those limits must be performed with appropriate restraint, and the conditions for the credibility of that extrapolation must be candidly stated.

If such restraint is not exercised with integrity, the results are likely to be meaningless at best and grossly misleading for those unprepared to assess the credibility of a given extrapolation. Mark Twain provides us with a very colorful example of the ridiculous conclusions that can be drawn from unrestrained extrapolation.

> In the space of one hundred and seventy-six years the Lower Mississippi has shortened itself two hundred and forty-two miles. This is an average of a trifle over one mile and a third per year. Therefore, any calm person, who is not blind or idiotic, can see that in the Old Oolithic Silurian Period, just a million years ago next November, the Lower Mississippi River was upward of one million three hundred thousand miles long, and stuck out over the Gulf of Mexico like a fishing-rod. . . . There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of fact. (from *Life on the Mississippi,* p. 155)

Professional scientists concur wholeheartedly with the thrust of Twain's conclusion: The offspring of unrestrained extrapolation is unmitigated nonsense.

Several matters of integrity are involved also in the manner in which one argues in favor of a particular theoretical model. We expect, for instance, that all relevant data will be given fair and adequate treatment—not only the supportive data but also the data which tell against the model. Anomalous or contradictory evidence may not be neglected or hidden. And if there are other phenomena or theories relevant to the one under evaluation, we expect the writer of the research report to bring such matters to the attention of the reader and to demonstrate how they strengthen or weaken the case.

This is particularly important when arguing in favor of a theory which makes strong claims for its superiority over a conventionally accepted alternative. Thus, in addition to the specific data and phenomena that are being investigated, the context of the investigation provided by other relevant data, phenomena and theories must be honestly engaged. Theorizing which, by conscious choice or by gross

neglect, fails to pay due attention to this context also fails to meet the standards of professional integrity which are necessary for the proper functioning of the scientific community.

Matters of Sound Judgment

Suppose, now, that there are two or more competing theories which claim to account for relevant data and to provide the best explanation for a given phenomenon. When scientists encounter such situations, they are called on to judge the relative merits of competing theories and to make choices on the basis of certain criteria. Assuming that the criteria for competent research and honest analysis have already been satisfied, what additional criteria does the scientific community employ in its evaluation of competing theories? Following the suggestion of Professor Ernan McMullin (History and Philosophy of Science Program, University of Notre Dame), we shall refer to these as *epistemic values*—the criteria used to evaluate the scientific merit of a theory, that is, its likelihood of being authentic knowledge concerning the actual state of affairs.

Just as there is no standard list of professional ethical values, there is no standard list of epistemic values. No professional scientific organization has undertaken, nor is any likely to undertake, the formulation of a program for scoring or grading a theoretical model. That's not the way value judgments are made. However, for the purpose of illustrating how the scientific community does go about the business of theory appraisal, let's list examples of relevant epistemic values. McMullin cites six—predictive accuracy, internal coherence, external consistency, unifying power, fertility and simplicity.[3] Our list is a somewhat modified version of his.

1. Cognitive relevance. The supply of diverse theories concerning some aspect of the composition, structure, behavior or history of the physical realm appears to be inexhaustible. But many of these theories (especially those proposed by persons who are not specialists in the area under consideration) fail to be of any value to natural science because they fail to have cognitive relevance—that is, they fail seriously to engage the relevant empirical evidence.

For example, college science teachers often receive personal letters or copies of privately published papers which claim to present grand theories that "solve the great riddles of the universe" and soon, purportedly, will replace the whole array of conventional scientific theories. These proposals, usually written by persons with little scientific training, have as one of their characteristic features the absence of meaningful contact with specific empirical data relevant to the phenomena under discussion. References to actual physical properties or behavior will be very general and vague at best. Such proposals, because of their lack of engagement with actual data, are of no use in the search for knowledge. They may themselves provide the data for an interesting psychological study, but they contribute nothing to our understanding of the physical world.

In addition to such obviously deficient proposals, numerous other theories about the physical world, especially about its formative history, have been constructed with little or no regard for the actual physical data which are readily available in published literature. The impetus for these theories may be the desire to reinforce some philosophical or political perspective or to provide support for some religious concept.

The elements which comprise the theory or historical scenario may be drawn from sources or traditions considered to be relevant and authoritative by a particular ideological community, from imaginative speculation or from both. However, even when such theories are proposed by intelligent and sincere persons, even by educated scholars, they provide little or no assistance in achieving the epistemic goal of the natural sciences.

Any theory that fails to engage the relevant empirical data fails to be a theory about the world as it is. Any theory about cosmic history, for example, that neglects the storehouse of empirically derived knowledge about the world as observed can be no more than a theory about some hypothetical world, a make-believe world designed to conform to a set of preconceived requirements. Natural science, on the other hand, seeks knowledge concerning the world in which we actually live. Its theories, therefore, must fully engage the results of empirical investigation or be judged to have little value.

2. *Predictive accuracy.* As a general rule, an authentically scientific theory provides a means of predicting the values of measurable properties or the behavioral characteristics that a given physical system should exhibit. The obvious question to ask is, How well do the predicted quantities or behavior patterns compare with those observed? Thus, in assessing the merit of one or more theoretical models, the criterion of predictive accuracy is surely relevant.

A model which displays greater predictive accuracy than some competing model would ordinarily be favored. There is, however, no absolute guarantee that the model favored on the basis of this single criterion will in the long run prove to be the better one. Ptolemy's geocentric model for the solar system may have had greater predictive accuracy than the heliocentric model suggested earlier by Aristarchus, but we now know that the heliocentric model, as improved later by Copernicus, Kepler and Newton, has clearly demonstrated its superiority in a number of different ways, including predictive accuracy.

A slight variation on this criterion may be applied to the investigation of formative history. Our concern here is not to predict what will happen in the future, but rather to construct a plausible scenario for what happened in the past, thereby forming what we are now able to observe. The relevant question to ask of a formative-history model is, How well does that historical reconstruction account for the present state of affairs? Would the proposed formative history lead us to expect all of the features that have already been observed? Would the model also predict the presence of features not yet investigated? And when investigators look for these predicted features, are they found to be there? If so, one's confidence in the credibility of that formative-history scenario is legitimately increased.

3. Coherence. To persons who have grown up in the environment of twentieth-century Western culture, it is perhaps self-evident that an adequate scientific theory should be internally coherent, that it should contain no elements that are logically inconsistent with other elements. We assume that the behavior of physical systems is rationally intelligible, and consequently we expect that our theoretical models for their behavior will be devoid of any internal contradictions.

But the criterion of coherence has an even broader scope. We expect that not only will the behavior of a particular system or category of systems be internally coherent, but also that the physical behavior of the entire empirically accessible universe will be rationally coherent. Patterns of physical behavior are presumed to be universally applicable—the same patterns in all places and at all times and for all relevant systems.

The law of energy conservation, for instance, applies not only here on earth, but within the Andromeda Galaxy as well; not only today, but three billion years ago in the quasar 3C 273 as well; not only for falling apples, but for nuclear reactions as well.

In the context of such expectations, then, we would ordinarily judge that a scientific theory should display not only an internal coherence, but also a coherence with respect to the entire spectrum of physical phenomena and their associated theoretical models. The adequacy of any theory will, in part, be judged on the basis of its coherence relative to other theories already judged to have merit.

4. Explanatory scope. The scientific community does not rest comfortably with unexplained coincidence. To cite a classic example, the Ptolemaic geocentric model for the solar system left two specific features of the apparent motion of planets without explanation. The phenomenon of limited elongation (restricted angular distance from the sun) exhibited by Mercury and Venus required the Ptolemaic model to constrain the epicycle centers for these two planets to lie along the earth-sun line. Why should their motion satisfy this constraint? No explanation. Within the Ptolemaic model this constraint

stood as an unexplained coincidence.

A similar appraisal applies to the observation that the fastest retrograde motion exhibited by Mars, Jupiter and Saturn always occurs when the planet is in opposition to the sun—another unexplained coincidence within the framework of Ptolemy's earth-centered geometry. In the sun-centered models of Copernicus and Kepler, however, both of these phenomena came to be recognized as natural consequences of the heliocentric geometry of the models. The explanatory scope, or inclusiveness, of the sun-centered models was greater than that of the Ptolemaic geocentric model. Unexplained coincidences were transformed into natural consequences.

Modern examples exist as well. For instance, the three-to-one dominance by mass of hydrogen over helium in the chemical composition of the physical universe is no longer considered to be a curious accident but rather the natural consequence of early cosmic history. The ability of the "standard model" in contemporary cosmology to explain this feature is considered to be a strong point in its favor. Theories with greater explanatory scope are generally judged to have greater epistemic merit.

5. Unifying power. The scientific community seeks not only to develop theories with sufficient explanatory scope to eliminate unexplained coincidences, it also seeks to unify what may once have been viewed as unrelated phenomena, each with their independent theories, into a single, more comprehensive theoretical framework. The effort by elementary particle theorists today to develop a single theory that will encompass the four (or will it be five?) fundamental forces provides a superb example of this goal. In the nineteenth century, James Clerk Maxwell successfully unified electrical and magnetic phenomena with his theory of electromagnetism. Today's theoretical physicists seek to develop yet another theory which will allow us to view the electromagnetic force, the weak nuclear force, the strong nuclear force and the gravitational force as but differing manifestations of a single "superforce."[4] It is remarkable how much progress toward this unification of forces has already been achieved.

But even on scales far less grand than that envisioned for "superforce" theory, those scientific theories which are able to unify diverse phenomena into one comprehensive theoretical framework will be favored over a collection of independent theories that treat each phenomenon in isolation from the others. The greater the unifying power of a theory, the better able it is, we judge, to demonstrate the inherent intelligibility of the physical world.

6. Fertility. The criterion, or epistemic value, of fertility is a bit more elusive than those already discussed. The five criteria cited above are concerned primarily with the question, How well does a given theory account for what we already know? Here, on the other hand, we are concerned to assess how well a theory functions to stimulate investigation in new areas, to suggest new ways of organizing our knowledge, to reveal relationships previously obscured, and the like. In each case the quality under scrutiny and assessment is the potency of a theory for stimulating the imagination and for initiating the propagation of a continuing line of helpful insights.

More epistemic values could be cited, though perhaps with diminished consensus among the philosophers and practitioners of science concerning their importance within the scientific enterprise. Among those already cited there is unavoidably some overlap. Furthermore, though we have chosen to arrange our list in a particular order, we make no claim that this represents the order of their functional importance.

With McMullin, we intend here only to call attention to the idea that theory assessment and theory choice in natural science is not principally a matter of mechanically scoring a theory according to some fixed set of self-evident rules, nor merely a matter of expressing one's personal opinion, but rather more like the process of making value judgments, something everyone does every day. These judgments are based on the system of *epistemic values* found within the scientific community—values inherited from previous generations, modeled by

senior members of the community, strengthened or modified by experience, applied in varying ways by members of the community, and permitting a healthy level of disagreement within the context provided by a broad foundation of consensus.

Extra-Scientific Matters

We have called attention to numerous constraints on the scientific enterprise that have evolved within the community of practicing scientists. The object of scientific investigation is not all of reality, only the physical world. The domain of natural science does not encompass all categories of questions about the physical world, only those questions concerning its inherent intelligibility. Operating within the boundaries of that domain, members of the scientific community are further constrained by their professional colleagues to meet the community's standards for craft competence, to carry out and report their research with ethical integrity, and to evaluate scientific theories on the basis of a communally developed epistemic value system.

But what, we now ask, do scientists do with their concepts and beliefs concerning the rest of reality? Must their scientific work be completely isolated from their concerns in the arenas of religion, philosophy, politics, economics, social institutions, personal ambitions and the arts? Won't these cultural, ideological, personal, religious and other extra-scientific concerns—concerns for matters outside of the scientific domain—have a discernible influence on one's scientific work? If so, what is the character and extent of this influence?

Identifying the roles played by extra-scientific concerns in the scientific enterprise is a complex and difficult task. It is an area of study that deserves continuing attention. For our present purposes we shall focus briefly on the function of religious commitments in scientific investigation. The term *religious commitment* must not be interpreted too narrowly, however. We do not wish, for instance, to restrict it to the Christian religion, not even to theism in general. Rather, we intend the term to represent the full spectrum of beliefs concerning the ultimate nature of reality, the existence or nonexistence of a transcendent deity, the significance of human life, and the relationship of the physical world to any transcendent beings or realms of reality. Thus twentieth-century Western naturalism is as much a religious commitment as is Christian theism.

First, religious commitments frequently serve as a stimulus for a scientist to select and carry out a particular program of research. Certain topics for investigation may be given priority because of their relevance to an investigator's world view—his or her "vision of reality." We see no reason to criticize or discourage this kind of influence. On the contrary, it would appear to be a wholly appropriate way to act with integrity in the context of one's religious commitments.

Second, religious commitments ought never lead a scientist to permit or encourage any reduction in the demands for craft competence or professional integrity. In order for the epistemic goal of natural science—the gaining of knowledge—to be achieved, each member of the community must honor the requirements for competence and integrity and must participate in the process of mutual discipline which functions to maintain those standards.

Third, religious commitments cannot be used as a warrant to ignore or to consciously violate the boundaries of the scientific domain. While the domain of one's personal concerns will inevitably extend beyond the boundaries of natural science, no scientist has the right to claim that natural science itself has the ability or authority to settle issues outside of the domain of inherent intelligibility that we described earlier.

For example, the oft-heard claims that natural science either confirms or discredits a theistic concept of divine governance or validates some particular concept of the status of the physical universe in relationship to deity is careless talk that exposes a failure to honor the boundaries of the scientific domain. Such a mischievous violation of domain boundaries is likely to be damaging to the credibility of authentic scientific results and, in the long run, will do a particular religious perspective no favor. Linking a specific scientific model to some religious belief system, for example, has the strategic disadvantage that a discrediting of that scientific model automatically calls into question the entire belief system attached to it. Alliances of religious belief and scientific theory should be formed only with great care and restraint.

Fourth, religious commitments, whether theistic or nontheistic, should not be permitted to interfere with the normal functioning of the epistemic value system employed within the scientific community. Great mischief is done when extra-scientific dogma is allowed to substitute for epistemic values such as cognitive relevance, predictive accuracy, coherence, explanatory scope, unifying power and fertility. And progress toward the goal of authentic knowledge is likely to be impeded when religious commitment is permitted to so skew the theory-evaluation process that one epistemic value takes inordinate precedence over all others.

The troublesome tendency with which we are dealing here is the temptation to employ natural science for the purpose of supporting preconceptions drawn from one's philosophical commitments or system of religious beliefs. But such an approach stands the scientific enterprise on its head and must be resolutely avoided. The goal of natural science is to gain knowledge, not to reinforce preconceptions. The purpose of empirical research is to discover what the physical world is really like, not to verify its conformity to our preferences. And the aim of scientific theorizing is to describe the actual character of the universe, not to force its compliance with our preconceived requirements

Science held hostage by any ideology or belief system, whether naturalistic or theistic, can no longer function effectively to gain knowledge of the physical universe. When the epistemic goal of gaining knowledge is replaced by the dogmatic goal of providing warrant for one's personal belief system or for some sectarian creed, the superficial activity that remains may no longer be called natural science.

It may be termed *world-view warranting* or *creed confirmation*, or one may put it into the category of *folk science*,[5] but it no longer deserves the label of *natural science* because it is no longer capable of giving birth to knowledge. Science held hostage by extra-scientific dogma is science made barren.

Are we then left with the implication that religious belief is held hostage by the results of an autonomous natural science? Emphatically not! Recall from our earlier discussion that science and religion have differing domains of concern. Consequently, each needs to learn from the other concerning what lies outside of its own domain. And those of us who wish to build a comprehensive world view must learn from both so that we may come to know not only the inherent intelligibility of the physical universe, but also its place in the whole of reality.

The scientific community seeks to gain knowledge in a manner that honors the religious diversity of its membership. When speaking on matters concerning the ultimate significance of the composition, structure or formative history of the universe, individual scientists may disagree sharply because of their differing religious commitments. However, when working within the restricted domain of natural science, scientists are able to function as a community united in the search for authentic knowledge concerning the inherent intelligibility of the physical world. The results of professional natural science belong to everyone; any attempt to declare them the exclusive property of one specific religious perspective must be rejected.

A question of direct concern to many Christians is, Does the Bible provide any data relevant to the construction or evaluation of theories in the natural sciences? Persons equally committed to the Christian faith differ widely in their judgment in this matter.[6] Some persons, for example, judge that the Bible provides data relevant to theories concerning the events, processes and chronology of the formative history of the universe. Others are convinced that it was never intended to address such concerns.

Resolution of these differences is not a simple matter. The Bible contains a rich diversity of forms of historical literature—forms often very different from what we are accustomed to. Furthermore, the agenda of the Bible's historical literature is authentic to its ancient Near Eastern cultural and religious context—a setting quite different from our modern Western world. Thus all persons, whether committed to the Christian faith or not, must exercise great care and caution in making statements about biblical data and its relevance to contemporary scientific theorizing.

Van Till, *The Fourth Day: What the Bible and the Heavens Are Telling Us about the Creation* (Grand Rapids: Eerdmans, 1986), especially chapters six and ten.

Chapter 2: The Path Most Traveled

[1] See, for example, the following: Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 2d ed. (Chicago: University of Chicago Press, 1970), and *The Essential Tension* (Chicago: University of Chicago Press, 1977), especially chapter thirteen, "Objectivity, Value Judgment, and Theory Choice," pp. 320-39; Larry Laudan, *Science and Values* (Berkeley: University of California Press, 1984); Ernan McMullin, "Values in Science," *PSA 1982* [Proceedings of the 1982 biennial meeting of the Philosophy of Science Association] (E. Lansing, Mich.: Philosophy of Science Association, 1983), Vol. 2; and Jerome R. Ravetz, *Scientific Knowledge and Its Social Problems* (New York: Oxford University Press, 1971).

[2] Our thanks to Professor Robert E. Snow for suggesting this set of four categories.

[3] Ernan McMullin, "Values in Science," pp. 1-25. For other discussions of scientific-theory evaluation, see W. H. Newton-Smith, *The Rationality of Science* (Boston: Routledge and Kegan Paul, 1981), pp. 226-32; Thomas S. Kuhn, *The Essential Tension* (Chicago: University of Chicago Press, 1977), pp. 320-39; and Del Ratzsch, *Philosophy of Science: The Natural Sciences in Christian Perspective* (Downers Grove, Ill.: InterVarsity Press, 1986), pp. 75-96.

[4] See Paul Davies, *Superforce* (New York: Simon and Schuster, 1984).

[5] We are using the term *folk science* in a manner similar to that of Jerome R. Ravetz in *Scientific Knowledge and Its Social Problems* (New York: Oxford University Press, 1971), especially pp. 386-97. Ravetz defines *folk science* as that "part of a general world-view, or ideology, which is given special articulation so that it may provide comfort and reassurance in the face of the crucial uncertainties of the world of experience" (p. 386).

[6] For a brief typology of positions on this question, see Ratzsch, *Philosophy of Science*, pp. 141-48.

Chapter 3: The Legend of the Shrinking Sun

[1] J. A. Eddy and A. A. Boornazian, "Secular Decrease in the Solar Diameter, 1836-1953," *Bulletin of the American Astronomical Society* 11 (1979):437. Note: this is only an abstract. The full text was never published.

[2] G. B. Lubkin, "Analyses of Historical Data Suggest Sun Is Shrinking," *Physics Today* 32, No. 9 (1979):17. The reference to the 1567 solar eclipse does not appear in the abstract (ref. 1), but can be found in this news report regarding Eddy and Boornazian's presentation.

[3] See the comments by Martin Schwarzschild reported in ref. 2. For an extensive review article which discusses these matters, see Gordon Newkirk, Jr., "Variations in Solar Luminosity," *Annual Review of Astronomy and Astrophysics*, 21 (1983):429-67.

[4] S. Sofia, J. O'Keefe, J. R. Lesh, and A. S. Endal, "Solar Constant: Constraints on Possible Variations Derived from Solar Diameter Measurements," *Science* 204 (1979):1306.

[5] Irwin I. Shapiro, "Is the Sun Shrinking?" *Science* 208 (1980):51.

[6] D. W. Dunham, S. Sofia, A. D. Fiala, D. Herald and P. M. Muller, "Observations of a Probable Change in the Solar Radius between 1715 and 1979," *Science* 210 (1980):1243.

[7] J. H. Parkinson, L. V. Morrison and F. R. Stephenson, "The constancy of the solar diameter over the past 250 years," *Nature* 288 (1980):548.

[8] R. L. Gilliland, "Solar Radius Variations over the Past 264 Years," *Astrophysical Journal* 248 (1981):1144.

[9] J. H. Parkinson, "New Measurements of the Solar Diameter," *Nature* 304 (1983):518.

[10] S. Sofia, D. W. Dunham, J. B. Dunham and A. D. Fiala, "Solar Radius Change between 1925 and 1979," *Nature* 304 (1983):522.

[11] C. Frohlich and J. A. Eddy, "Observed Relation between Solar Luminosity and Radius" [a paper presented at an international conference sponsored by the Committee on Space Research, July 1984 in Graz, Austria].

[12] Russell Akridge, "The Sun Is Shrinking," *Impact* No. 82 (Institute for Creation Research, April 1980), pp. iii, iv.

[13] See Thomas G. Barnes, "Evidence Points to a Recent Creation," *Christianity Today*, October 8, 1982, pp. 34-36.

[14] See *ORIGINS Film Series Handbook* (Phoenix, Ariz.: Films for Christ Association, 1983), pp. 11-12.

[15] In order to give due recognition to an important symmetry, we should note that just as scientific creationism functions as the folk science of contemporary Christian fundamentalism, so also naturalistic evolutionism functions as the folk science of modern Western naturalism. In each case, selected results of scientific investigation are interpreted in such a way that they may be employed to bolster a creedal tenet of a world view or ideology.

[16] Walter T. Brown, Jr., "The Scientific Case for Creation," *Bible-Science Newsletter*, July, 1984, p. 14.

[17] Henry M. Morris, *The Biblical Basis of Modern Science* (Grand Rapids: Baker Book House, 1984), p. 164.

[18] Hilton Hinderliter, "The Shrinking Sun: A Creationist's Prediction, Its Verification, and the Resulting Implications for Theories of Origins," *Creation Research Society Quarterly* 17 (1980):57; "The Inconsistent Sun: How Has It Been Behaving, and What Might It Do Next?" *Creation Research Society Quarterly* 17 (1980):143.

[19] See Lubkin, "Analyses."

[20] See Newkirk, "Variations."

[21] Hinderliter, "The Shrinking Sun," p. 57.

[22] Ibid., p. 59.

[23] Ibid.

[24] See Chapter IV, "Stellar Evolution and Nucleosynthesis," in *A Source Book in Astronomy and Astrophysics, 1900-1975*, edited by Kenneth R. Lang and Owen Gingerich (Cambridge, Mass.: Harvard University Press, 1979). This collection of original papers and editorial commentary provides an excellent overview of this important episode in the history of astrophysics.

[25] Hinderliter, "The Shrinking Sun," p. 59.

[26] James Hanson, "The Sun's Luminosity and Age," *Creation Research Society Quarterly* 18 (1981):27.

[27] See refs. 4 and 5.