own theory, Dennett trots out a series of nonissues, and ignores the real problems or anomalies that have become so unavoidable for Darwinian theory in recent years. After dismissing Gould, who criticizes not Darwinism per se but the Dawkins version of it, as motivated by what he claims is Gould's secret anti-evolutionary sentiments (Gould, he says, is really looking for miracles rather than scientific explanations), Dennett goes on to discuss what he refers to as the "major charges" against Darwinism. "A review of all the major charges that have been leveled against" Darwinism, he writes (Dennett, 1995b), reveals that "its dominion over every corner of biology is more secure than ever" (p. 312). All the "major charges" Dennett discusses, however, are strawpersons, because no one, as far as I know in the discourse on contemporary evolutionary theory, takes any of them to be a pressing issue or to present a challenge to Darwinian theory of any stripe. Dennett puts his challenges into two groups. The first, which has the theory of "panspermia" as the central example, he says includes "harmless if unwelcome heretical possibilities" (p. 331), and the second, which includes Teilhard de Chardin's spiritual, directed theory of evolution and Lamarck's genetic transmission of acquired traits, he says would be "fatal to Darwinism" if true. He also goes over some of the debate within the Darwinian discourse on units of selection (e.g., is it organisms or genes that are selected?), which he says has no "dire implications" for Darwinism whichever way it turns out.

The theory of panspermia, a theory about the origin of life that has been argued by people such as Hoyle and Crick, suggests that life did not originate on Earth but came to Earth, for example, as bacterial spores, from some other place in space. Because the origin of life is outside the scope of Darwinian theory by definition, whether life originated on Earth changes nothing for Darwinism—Darwinism starts with life up and running to begin with and so the whole issue is irrelevant with respect to the veracity of its claims. Dennett's discussion of de Chardin and Lamarck is as irrelevant, if not more so, than the question of panspermia. Chardin wrote a popular book, published after his death in the mid-1950s, in which he attempted to reconcile his Christianity with evolutionary theory. Dennett (1995b) is correct when he says that "[i]t is fair to say that in the years since this work was published, it has become clear to the point of unanimity among scientists that Teilhard offered nothing serious in the way of an alternative to orthodoxy" (p. 320). Then why, except as a strawperson, is Chardin brought up as a "major challenge" to Darwinism, or likewise, Lamarck's theory of the inheritance of acquired characters? The general fact that the long necks of giraffes are not the consequence of their ancestors stretching their necks to reach tall trees is certainly also accepted unanimously by evolutionary theorists.

Running through these strawperson arguments while avoiding the "big problems" of evolution, Dennett attempts to pass Darwinism off as an unassailable theory—*the* theory of evolution, true and complete, a theory with all its real challenges behind it. Of controversies like the one surrounding the units of selection, he pictures them all as squabbles within the Darwinian discourse. "No

matter which side wins," Dennett (1995b) says, the outcome will not undo the basic Darwinian idea" (p. 34). Besides, Dennett asserts, "only a theory with the logical shape of Darwin's" could possibly work (p. 70).

It is after painting a picture in which no one except a Creationist or some other nonscientific thinker, he would have the reader believe, could do other than accept Darwinian theory as unassailable, that Dennett attempts to establish the supposed unequivocal truth of his own theory by association. In this way he tries to make a preemptive strike against would-be critics of selfish algorithm theory, branding them, by implication, as anti-evolutionary or anti-scientific thinkers. "It is no coincidence," Dennett writes (1995b) "as I have shown, that those who deplore Artificial Intelligence are also those who deplore evolutionary accounts of human mentality" (p. 370). With this, Dennett would like to convince the reader that those who oppose his algorithmic account of agency and mind in nature are opposed to it for the same reasons he says that people are opposed to Darwinism, namely, because it explains too much—it trespasses on sacred ground they do not want explained. The actual situation, of course, is considerably different.

It Is the Situational Logic That Needs Explaining

The problem with Dennett's selfish algorithm theory is not that it explains too much, but that, like Darwinism in general as the theory of evolution, *it assumes too much and explains too little*. It is the Cartesian miracles, the immaterial entities, the ad hoc animism that Dennett's theory begins with, its failure to connect with the empirical facts and failure to address the major problems of evolutionary theory that are its downfall. By uncritically aligning himself with Darwinian theory in general, and then adding to it the more recently packaged idealist reductionism of Dawkins, Dennett starts with postulates of incommensurability and the fatal problems that plague even the most moderate, sensible forms of Darwinism that follow from them, and then only compounds the difficulty. The "logical shape" of Darwinian theory, the idea that evolution follows from natural selection, and the situational logic it entails, is a problem for Darwinian theory, not because there is a question about the fact of natural selection, but because it precisely the situational logic from which selection follows as a consequence, given the Boltzmannian physics Darwinian theory assumes, that needs explaining.

A theory with the "logical shape" of Darwinism, and, in this case Dennett's, which begins with the postulates of incommensurability at its core, rather than being a theory with the only logical shape that can do the requisite job, as Dennett asserts, is a theory that precisely by virtue of its logical shape is prohibited from doing so. It is the core of Darwinian theory itself that negates even the possibility of Dennett's (1995b) claims that Darwinism's "dominion over every corner of biology" is secure, or that natural selection is a theory like "universal acid" that eats through or explains everything (p. 312). In particular, as noted above, the active, end-directed striving,

or epistemic ordering, of living things is an implicate of the fecundity principle, and the fecundity principle is a precondition from which natural selection is seen to follow. Because evolution is defined and explained, on the Darwinian view, as a consequence of natural selection, this puts the fecundity principle, and thus the active, end-directed ordering of living things, by definition, beyond the explanatory reach of Darwinian theory. Instead it is simply assumed in advance, against the laws of physics, as a requirement for the explanatory framework of Darwinian theory to work (e.g., Swenson, 1991a). As Barham (1996) has aptly put it, Darwinian theory "begs the question" rather than answering it (p. 237). By taking evolution out of its universal context and assuming the incommensurability between biology, psychology, and physics, or the view of the two incommensurable rivers, Darwinian theory thus begins, like all other Cartesian offspring, with a fundamental and insurmountable anomaly at its core—an anomaly that can only lead to more anomalies, the defining trait of a degenerating research program.

The problem compounds from the active, opportunistic ordering of living things, the *sine qua non* of the living, to the problem of planetary evolution itself. As noted, one of the most important empirical facts that has come to be recognized in recent decades is that the Earth at the planetary level evolves as a single global (autocatakinetic) system or entity (e.g., Cloud, 1988; Margulis & Lovelock, 1974; Schwartzmann, Shore, Volk, & McMenamin, 1994, Swenson & Turvey, 1991; Vernadsky, 1929/1986) on which all the ordinary evolutionary objects of Darwinian theory, as well as cultural systems depend (e.g., for a steady and reliable supply of oxygen put into the atmosphere and maintained by life itself at the planetary level over geological time; see Swenson, 1991a; Swenson & Turvey, 1991). Because the evolution, development, and persistence of all higher ordered life, and in particular, the intentional dynamics by which it is distinguished, has thus depended and continues to depend on the prior existence and persistence of life at the planetary level, the planetary system as a single autocatakinetic entity is rightfully considered as the fundamental unit of terrestrial evolution, without an understanding of which the more usual objects of evolutionary study, as internal component productions or functions of it, can never be understood.

This presents a major problem for Darwinian theory, because from the Darwinian view, the planetary system as a whole, by definition, cannot be considered as a unit of evolution or to evolve at all (e.g., Dawkins, 1982; Maynard-Smith, 1988). Darwinian theory, which defines evolution as the consequence of natural selection acting on a competing population of replicating entities of many cannot address or even recognize planetary evolution because there is no replicating population of competing Earth systems on which natural selection can act—*the Earth evolves as a population of one*. In addition to the active striving, or active ordering, of living things in general, this puts planetary evolution outside the explanatory framework of Darwinian theory, and so too, as a consequence, the evolution of living things in general which, as internal component productions or functions, are entirely dependent on it. This particular problem ("the problem of the population of one";

e.g., Swenson, 1991a) extends beyond planetary evolution as a whole to evolutionary dynamics in general from simple physical systems to the origins and evolution of culture (e.g., see Swenson, 1989a, 1989b, 1991b, in press-a; Swenson & Turvey, 1991; for relevant discussion, see also Carneiro, 1970, 1981, 1987; Goerner, 1994; Lichtenstein, 1995; and Robb, 1990, 1991).

In general terms, the most fundamental problem with Darwinian theory is that it has no principled account of spontaneous ordering, or autocatakinetics, of which the evolutionary dynamics that are part of its theory, such as the fecundity principle and natural selection, are seen to be productions or consequences, and that, in addition, this is a remedyless circumstance within the Darwinian paradigm. It is proscribed by the distinguishing core itself, and to change the core, by definition, is to change the paradigm. Among the particularly remarkable things about Dennett's book is the fact that, given his intention to provide an evolutionary or naturalized basis for the epistemic dimension of the world or "mind" in nature, he fails to mention the well-established discourse on "evolutionary epistemology," the stated intention of which, although typically devoid of the neo-Pythagorean reductionism of Dennett or Dawkins, is the same thing (e.g., Callebaut & Pinxten, 1987; Campbell, 1987; Radnitzky & Bartley, 1987). Although evolutionary epistemology, to the extent that it is grounded on Darwinian theory, runs into the same generic problems as Dennett's scheme (see Swenson, in press-a, in press-b), it is instructive to note that in his opus on the task of naturalizing or evolutionizing the epistemic dimension of the world written more than a quarter century ago, Konrad Lorenz (1973), one of the founders of evolutionary epistemology, wrote that the aspect of life "most in need of explanation, is that, in apparent contradiction to the laws of probability, it seems to develop ... from the more probable to the less probable, from systems of lower order to higher order" (p. 20).

As the previous section of this article reveals, we now have such an explanation. The law of maximum entropy production, when coupled with the balance equation of the second law and the general facts of autocatakinetics, shows why, rather than living in a world where order production is infinitely improbable, we live in and are products of a world that can be expected to produce as much order as it can. It shows how the two otherwise incommensurable rivers, physics on the one hand and psychology and biology on the other, are part of the same universal process—how the fecundity principle, and the intentional dynamics or epistemic ordering it entails, are special cases of an active, end-directed world opportunistically filling dynamical dimensions of space–time as a consequence of universal law. The epistemic dimension—the urgency toward existence, in Leibniz's (1697/1969) terms, characterizing the intentional dynamics of living things and expressed in the fecundity principle, and the process of evolution writ large—is thus not only commensurable with first principles, but a direct manifestation of them. With this understanding, the anomalous facts of evolution (the "big problems" of evolutionary theory) are dissolved, and a principled basis is provided for placing the active, epistemic

dimension of the world back in its universal context, uniting living things and their environments, knower and known, or self and other as reciprocal parts of a single dynamical or universal process.

This view, nomologically grounded and empirically robust, which shows the deep and ineluctable relation between physics, biology, and psychology, provides more than a mere "falsification" of the core premises of Dennett's dualistic reductionism in the ordinary sense (e.g., that living things, or "mind" in nature "defy" or work against universal law). It meets the richer criteria for paradigm elimination or replacement of Lakatos's (1970) "sophisticated falsificationism" that builds on the distinction between "degenerating" versus "progressive" theories (see Appendix). Relative to "degenerating" theories, "progressive" theories, or paradigms, are solution generators. They are not just explanations, but provide explanations, or frameworks that produce more explanations (see Dyke, in press), and the measure that sophisticated falsificationism seeks is thus a measure of productivity or explanatory robustness. In simplest terms, according to Lakatos's criteria, for one theory or paradigm to eliminate or replace another, the new theory or paradigm must have additional or excess empirical content over the older one (e.g., something improbable according to the old theory becomes expected or probable according to the new theory); the replacing theory must explain or subsume the unrefuted content of the older theory; and some of the additional empirical content of the replacing theory must be confirmed. With respect to Darwinian theory, and indeed Cartesianism in general and all its dualist offspring, as I hope I have shown, these criteria have already been well met.

REFERENCES

Aristotle (1947). De anima. In R. McKeon (Ed.), *Introduction to Aristotle* (pp. 163–329). New York: Random House.

Aristotle (1961). *Metaphysics*. (W. Warrington, Trans.). New York: Dutton.

Barham, J. (1996). A dynamical model of the meaning of information. *Biosystems, 38*, 235–241.

Bertalanffy, L. von (1952). *Problems of life*. London: Watts.

Blumenfeld, D. (1981). Leibniz's theory of the striving possibles. In R. Woolhouse (Ed.) *Leibniz: Metaphysics and philosophy of science* (pp. 77–88). Oxford, England: Oxford University Press.

Blyth, E. (1835). An attempt to classify the "varieties" of animals. *Magazine of Natural History (London), 8*, 40–53.

Boltzmann, L. (1964). *Lectures on gas theory* (S. Brush, Trans.). Berkeley: University of California Press. (Original work published 1896)

Boltzmann, L. (1974). The second law of thermodynamics. In *Ludwig Boltzmann, Theoretical physics and philosophical problems* (S. G. Brush, Trans.). Boston: D. Reidel. (Original work published 1886)

Bowler, P. (1988). *The non-Darwinian revolution: Reinterpreting a historical myth*. Baltimore: Johns Hopkins University Press.

Bowler, P. (1989). *Evolution: The history of an idea*. Berkeley: University of California Press.

Bunge, M. (1979). *Causality and modern science*. New York: Dover.

Callebaut, W., & Pinxton, R. (1987). *Evolutionary epistemology: A multiparadigm program*. Dordrecht, Holland: D. Reidel.

Calvin, W. H. (1986). *The river that flows uphill.* New York: Macmillan.
Campbell, B. G. (1985). *Humankind emerging.* Boston: Little, Brown.
Campbell, D. T. (1987). Evolutionary epistemology. In G. Radnitzky & W. W. Bartley III (Eds.), *Evolutionary epistemology, rationality, and the sociology of knowledge* (pp. 47–89). La Salle, IL: Open Court.
Carneiro, R. (1970). A theory of the origin of the state. *Science, 169,* 733–738.
Carneiro, R. (1972). The devolution of evolution. *Social Biology, 19,* 248–258.
Carneiro, R. (1981). The chiefdom: Precursor of the state. In G. Jones & R. Kautz (Eds.), *The transition to statehood in the new world* (pp. 37–79). Cambridge, England: Cambridge University Press.
Carneiro, R. (1987). Village splitting as a function of population size. In L. Donald (Ed.) *Themes in ethnology and culture history, Essays in honor of David F. Aberle* (pp. 94–124). Meerut, India: Archana.
Carnot, S. (1960). *Reflections on the motive power of heat and other papers* (pp. 3–22). New York: Dover. (Original work published 1824)
Cassirer, E. (1950). *The problem of knowledge: Philosophy and history since Hegel.* New Haven, CT: Yale University Press. (Original work published 1940)
Chambers, R. (1969). *Vestiges of the natural history of creation.* New York: Humanities. (Original work published 1844)
Clausius, R. (1865/1960). Ueber Vershiedene für die Anwendung bequeme formen der Hauptgleichungen der mechanischen warmetheorie [On several forms for main comparisons of mechanical thermodynamic theory that are easy to use]. *Annalen der Physik und Chemie,* 7, 389–400. (Original work published 1865)
Cloud, P. (1988). *Oasis in space: Earth history from the beginning.* New York: Norton.
Cloud, P. (1989). Biological evolution through the geologic eons. In R. A. Meyers (Ed.), *Encyclopedia of physical science and technology* (pp. 35–51). San Diego, CA: Academic.
Darlington, C. D. (1961). *Darwin's place in history.* New York: Macmillan.
Darnell, J., Lodish, H., & Baltimore, D. (1986). *Molecular cell biology.* New York: Freeman.
Darwin, C. (1937). *On the origin of species by means of natural selection or the preservation of favored races in the struggle for life.* New York: Appleton-Century. (Original work published 1859)
Dawkins, R. (1989). *The selfish gene.* England: Oxford University Press. (Original work published 1976)
Dawkins, R. (1982). *The extended phenotype.* San Francisco: Freeman.
Dawkins, R. (1986). *The blind watchmaker.* New York: Freeman.
Dawkins, R. (1995). *River out of Eden: A Darwinian view of life.* New York: Basic Books.
Dennett, D. (1991). *Consciousness explained.* New York: Little, Brown.
Dennett, D. (1995a, May/June). Darwin's dangerous idea. *The Sciences, 35,* 34–40.
Dennett, D. (1995b). *Darwin's dangerous idea: Evolution and the meanings of life.* New York: Simon & Schuster.
Depew, D. (in press). Developmentalism vs. Darwinism: Prospects for reunion. In G. van de Vijver, S. Salthe, & M. Delpos (Eds.), *Evolutionary systems.*
Depew, D., & Weber, B. (1995). *Darwinism evolving.* Cambridge, MA: MIT Press.
Dyke, C. (in press). Heuristics for ecological interaction. *Advances in Human Ecology.*
Dyke, C. (1996). *Very pretty. Is that how the organism does it?* Manuscript in preparation.
Eddington, A. (1958). *The nature of the physical world.* Ann Arbor, MI: Ann Arbor Paperbacks.
Eisley, L. (1979). *Darwin and the mysterious Mr. x: New light on the evolutionists.* New York: Dutton.
Fisher, R. (1958). *The genetical theory of natural selection.* New York: Dover. (Original work published 1930)
Fleischaker, G. R. (1990). Symbols and dynamics: Two different system levels. *Perceiving–acting workshop review* (Technical report of the Center for the Ecological Study of Perception and Action), 5(2), 30–32.
Gibson, J. J. (1986). *The ecological approach to visual perception.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc. (Original work published 1979)
Gilson, E. (1984). *From Aristotle to Darwin and back again* (J. Lyon, Trans.). South Bend, IN: University of Notre Dame.

Goerner, S. (1994). *Chaos and the evolving ecological universe.* New York: Gordon & Breach.

Gould, S. J., & Lewontin, R. (1979). San Marco and the Panglossian paradigm: A critique of the adaptionist programme. *Proceedings of the Royal Society of London B, 205,* 581–598.

Goodwin, B. (1982). Development and evolution. *Journal of Theoretical Biology, 97,* 43–55.

Goodwin, B. (1994). *How the leopard got its spots.* New York: Scribner's.

Grene, M. (1974). *The knower and the known.* Berkeley: University of California Press. (Original work published 1966)

Hoffmeyer, J. (in press). The unfolding semsiosphere. In G. van de Vijver, S. Salthe, & M. Delpos (Eds.), *Evolutionary systems.*

Hull, D. (1973). *Darwin and his critics.* Cambridge, MA: Harvard University Press.

Huxley, A. (1982). How far will Darwin take us? In D. Bendell (Ed.), *Evolution from molecules to men* (pp. 3–22). Cambridge, England: Cambridge University Press.

Huxley, T. (1970). Evolution in biology. In T. Huxley, *Darwiniana: Essays.* New York: AMS. (Original work published 1878)

Kim, N., Turvey, M. T., & Carello, C. (1993). Optical information about the severity of upcoming collisions. *Journal of Experimental Psychology, 19(1),* 179–193.

Kugler, P., Turvey, M. T., Carello, C., & Shaw, R. E. (1985). The physics of controlled collisions: A reverie about locomotion. In W. Warren & R. E. Shaw (Eds.), *Persistence and change* (pp. 195–229). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Kuhn, T. (1962). *The structures of scientific revolutions.* Chicago: University of Chicago Press.

Lakatos, I. (1970). Falsification and the methodology of scientific research programmes. In I. Lakatos & A. Musgrave (Eds.), *Criticism and the growth of scientific knowledge* (pp. 91–195). Cambridge, XXXXX: Cambridge University Press.

Lee, D. (1980). A theory of visual control of braking based on information about time-to-collision. *Perception, 5,* 437–459.

Leibniz, (1925). On the ultimate origination of things. In R. Latta (Trans.),*The monodology and other philosophical writings* (pp. 337–354). London: Oxford University Press. (Original work published 1697)

Leibniz, G. W. (1969). On the radical origination of things. In L. E. Loemker (Ed.), *G. W. Leibniz philosophical papers and letters* (pp. 486–491). Dordrecht, Holland: D. Reidel. (Original work published 1697)

Lenoir, T. (1982). *The strategy of life.* Chicago: University of Chicago Press.

Levins, R., & Lewontin, R. (1985). *The dialectical biologist.* Cambridge, MA: Harvard University Press.

Lewontin, R. (1992). *Biology as ideology: The doctrine of DNA.* New York: HarperCollins.

Lichtenstein, B. (1995). Evolution or transformation: A critique and alternative to punctuated equilibrium. In D. Moore (Ed.), *Best papers proceedings: The 55th annual meeting of the academy of management science* (pp. 291–295). Vancouver, BC, Canada: Academy of Management.

Lorenz, K. (1973). *Behind the mirror: A search for a natural history of human knowledge.* New York: Harcourt Brace.

Lovejoy, A. (1968). The argument for organic evolution before the *Origin of species,* 1830–1858. In B. Glass, O. Temkin, & W. Strauss, Jr. (Eds.), *Forerunners of Darwin: 1745–1859* (pp. 356–414). Baltimore: Johns Hopkins University Press.

Lovejoy, A. (1978). *The great chain of being.* Cambridge, MA: Harvard University Press. (Original work published 1936)

Løvtrup, S. (1987). *Darwinism: The refutation of a myth.* London: Croom Helm.

Malthus, T. R. (1992). *An essay on the principle of population.* Cambridge, England: Cambridge University Press. (Original work published 1803)

Margulis, L. (1981). *Symbiosis in cell evolution.* San Francisco: Freeman.

Margulis, L., & Lovelock, J. (1974). The biota as ancient and modern modulator of the Earth's atmosphere. *Tellus, 26,* 1–10.

Margulis, L., & Sagan, D. (1995). *What is life?* New York: Simon & Schuster.

Matthew, P. (1971). Notes on natural selection. In H. McKinney (Ed.), *Lamarck to Darwin: Contributions to evolutionary biology 1809–1859* (pp. 29–42). Lawrence, KS: Coronado. (Original work published 1831)

Maxwell, J. C. (1970). *Theory of heat.* Westport, CT: Greenwood. (Original work published 1872)

Maynard-Smith, J. (1988). Evolutionary progress and levels of selection. In M. Nitecki (Ed.), *Evolutionary progress* (pp. 219–230). Chicago: University of Chicago Press.

Mayr, E. (1969). Cause and effect in biology. In C. H. Waddington (Ed.), *Towards a theoretical biology* (Vol. 1, pp. 42–54). Chicago: Aldine.

Mayr, E. (1976). Teleological and teleonomic: A new analysis. In E. Mayr (Ed.), *Evolution and the diversity of life: Selected essays, Ernst Mayr* (pp. 383–404). Cambridge, MA: Belknap.

Mayr, E. (1980). Prologue: Some thoughts on the history of the evolutionary synthesis. In E. Mayr & W. B. Provine (Eds.), *The evolutionary synthesis* (pp. 1–48). Cambridge, MA: Harvard University Press.

Mayr, E. (1985). How biology differs from the physical sciences. In D. Depew & B. Weber (Eds.), *Evolution at a crossroads* (pp. 43–63). Cambridge, MA: MIT Press.

Merchant, C. (1980). *The death of nature.* San Francisco: Harper & Row.

Naudin, C. (1852). Considérations philosophique sur l'espéce et la variété. *Horticulture Review, 4,* 102–109.

Orr, H. (1996). Dennett's dangerous idea. *Evolution, 50*(1), 467–472.

Osborn, H. F. (1984). *From the Greeks to Darwin: An outline of the development of the evolution idea.* New York: Macmillan.

Peck, A. (1996). *Hydrodynamics, reactive forces, and the autocatakinetics of hearing.* Manuscript in preparation.

Philip, J. A. (1966). *Pythagoras and early Pythagoranism.* Toronto: University of Toronto Press.

Plato (1949). *Timaeus* (G. R. Morrow, Trans.). New York: Liberal Arts.

Polanyi, M. (1968). Life's irreducible structure. *Science, 160,* 1308–1312.

Popper, K. (1985). *Unended quest: An intellectual autobiography.* La Salle, IL: Open Court.

Prigogine, I. (1978). Time, structure, and fluctuations. *Science, 201,* 777–785.

Radnitzky, G., & Bartley, W. W. III. (1987). *Evolutionary epistemology, rationality, and the sociology of knowledge.* La Salle, IL: Open Court.

Richards, R. J. (1992). *The meaning of evolution: The morphological construction and ideological reconstruction of Darwin's theory.* Chicago: University of Chicago Press.

Robb, F. (1990). On the application of the theory of emergence and the law of maximum entropy production to social processes. *Systems Practice, 3,* 389–399.

Robb, F. (1991). Are institutions entities of a natural kind? A conseration of the outlook for mankind. In C. Negoita (Ed.), *Cybernetics and applied systems* (pp. 149–162). New York: Marcel Dekker.

Ruse, M. (1979). *The Darwinian revolution.* Chicago: University of Chicago Press.

Salthe, S. (1972). *Evolutionary biology.* New York: Holt, Rinehart & Winston.

Salthe, S. (1985). *Evolving hierarchical systems.* New York: Columbia University Press.

Salthe, S. (1994). *Evolution and development.* Cambridge, MA: MIT Press.

Schneer, C. (1960). *The evolution of physical science.* New York: Grove.

Schopf, J. W. (Ed.). (1983). *Earth's earliest biosphere.* Princeton, NJ: Princeton University Press.

Schrödinger, E. (1945). *What is life?* New York: Macmillan.

Schwartzman, D., Shore, S., Volk, T., & McMenamin, M. (1994). Self-organization of the Earth's biosphere—Geochemical or geophysiological? *Origins of Life and Evolution of the Biosphere 24,* 435–450.

Schweber, S. S. (1985). The wider British context of Darwin's theorizing. In D. Kohn (Ed.), *The Darwinian heritage* (pp. 35–69). NJ: Princeton University Press.

Singer, C. (1959). *A short history of scientific ideas to 1900.* Oxford, England: Clarendon.

Sober, E. (1984). *The nature of selection: Evolutionary theory in philosophical focus.* Cambridge, MA: Bradford.

Spencer, H. (1852). The social organism. *The Westminster Review, 57,* 468–501.
Spencer, H. (1857, April). Progress: Its law and cause. *Westminster Review,* pp. 445–485.
Spencer, H. (1862). *First principles.* London: Williams & Norgate.
Spencer, H. (1882). *First principles* (4th ed.). New York: Appleton.
Spencer, H. (1892a). *Essays: Scientific, political, and speculative.* New York: Appleton.
Spencer, H. (1892b). The development hypothesis. In *Essays: Scientific, political, and speculative* (pp. 4–34). New York: Appleton. (Original work published 1852)
Swenson, R. (1988). Emergence and the principle of maximum entropy production: Multi-level system theory, evolution, and non-equilibrium thermodynamics. *Proceedings of the 32nd Annual Meeting. ISGSR,* 32.
Swenson, R. (1989a). Emergent evolution and the global attractor: The evolutionary epistemology of entropy production maximization. *Proceedings of the 33rd Annual Meeting of the ISSS, 33*(3), 46–53.
Swenson, R. (1989b). Engineering initial conditions in a self-producing environment. In M. Rogers & N. Warren (Eds.), *A delicate balance: Technics, culture and consequences* (IEEE Catalog No. 89CH2931–4, pp. 68–73). Los Angeles: Institute of Electrical and Electronic Engineers.
Swenson, R. (1989c). Gauss-in-a-box: Nailing down the first principles of action. *Perceiving-acting workshop review* (Technical report of the Center for the Ecological Study of Perception and Action), *5,* 60–63.
Swenson, R. (1990a). Evolutionary systems and society. *World Futures, 30,* 11–16.
Swenson, R. (1990b). A robust ecological physics needs an ongoing crackdown on makers conjured out of thin air. *Perceiving-acting workshop review* (Technical report of the Center for the Ecological Study of Perception and Action), *6,* 35–38.
Swenson, R. (1991a). End-directed physics and evolutionary ordering: Obviating the problem of the population of one. In F. Geyer (Ed.), *The cybernetics of complex systems: Self-organization, evolution, and social change* (pp. 41–60). Salinas, CA: Intersystems.
Swenson, R. (1991b). Order, evolution, and natural law: Fundamental relations in complex system theory. In C. Negoita (Ed.), *Cybernetics and applied systems* (pp. 125–148). New York: Marcel Dekker.
Swenson, R. (1992). Autocatakinetics, yes—Autopoiesis, no: Steps towards a unified theory of evolutionary ordering. *International Journal of General Systems, 21,* 207–228.
Swenson, R. (1997). Thermodynamics and evolution. In G. Greenberg & M. Haraway (Eds.), *The encyclopedia of comparative psychology.* New York: Garland.
Swenson, R. (in press-a). Autocatakinetics, evolution, and the law of maximum entropy production: A principled foundation towards the study of human ecology. *Advances in Human Ecology.*
Swenson, R. (in press-b). Spontaneous order, evolution, and autocatakinetics: The nomological basis for the emergence of meaning. In G. van de Vijver, S. Salthe, & M. Delpos (Eds.), *Evolutionary systems.*
Swenson, R. (in press-c). *Spontaneous order, evolution, and natural law: An introduction to the physical basis for an ecological psychology.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
Swenson, R., & Turvey, M. T. (1991). Thermodynamic reasons for perception–action cycles. *Ecological Psychology, 3,* 317–348.
Thomson, W. (1852a). On the dynamical theory of heat, with numerical results deduced from Mr. Joule's equivalent of a thermal unit, and M. Regnault's observations on steam. *Philosophical Magazine and Journal of Science, 4,* 9–21.
Thomson, W. (1852b). On the universal tendency in nature to the dissipation of mechanical energy. *Philosophical Magazine and Journal of Science, 4,* 304–306.
Turvey, M. T., & Shaw, R. E. (1995). Towards an ecological physics and a physical psychology. In R. Solso & D. Massaro (Eds.), *The science of mind: 2001 and beyond* (pp. 144–169). Oxford, England: Oxford University Press.
Vernadsky, V. (1986). *The biosphere.* London: Synergetic. (Original work published 1929)
Waddington, C. (1975). *The evolution of an evolutionist.* Scotland: University of Edinburgh Press.

Wallace, A. C. (1858). On the tendency of varieties to depart from the original type. *Journal of the Proceedings of the Linnean Society, 3*, 53–62.

Weber, B., & Depew, D. (1996). Natural selection and self-organization: Dynamical models as clues to a new evolutionary synthesis. *Biology and Philosophy, 11*, 35–64.

Williams, G. (1966). *Adaptation and natural selection.* Princeton, NJ: Princeton University Press.

APPENDIX

Theory falsification, to review briefly, is an idea popularized by Popper as the demarcation criterion between scientific and nonscientific theories and as the main criterion for theory elimination. Although it had long been held that theories could be proven by collecting confirming instances, it was Popper who underscored the fact that no matter how many such instances were discovered, a theory could never be proved true in this way. One could keep discovering more and more white swans, for example, in the quest to prove the claim that "all swans are white," but this would never assure that there were no black swans. On the other hand, discovering one black swan would falsify the claim that all swans are white. A theory is scientific, said Popper, if it is capable of falsification.

Lakatos (1970), recognizing that in practice scientists typically protect the "hard core" assumptions of their "research programs" (or *paradigms*, in Kuhn's terms) from falsification by invoking auxiliary assumptions or by redefining terms to deal with anomalies, introduced the idea of "sophisticated falsificationism" to deal with this problem. Popper himself had been critical of the practice of saving a theory from falsification by ad hoc hypotheses, or simply by linguistic devices, such as redefining terms. Lakatos's sophisticated falsificationism was developed precisely to deal with the problem of the admissability of auxiliary hypotheses and the redefinition of terms, and toward this end he introduced the distinction between "progressive" and "degenerating" problemshifts. A *problemshift* (or series of theories) is progressive if by adding new auxiliary hypotheses (or changing the definition of terms), it possesses additional or excess empirical content when compared to its predecessor. A problemshift is negative or degenerating if it employs auxiliary assumptions or redefinitions merely to save the hard core of a theory without adding additional empirical content—it makes additional moves with the result of saving the theory without any additional empirical content (usually, in fact, the theory, more highly constrained, comes away with less).

Sophisticated falsificationism thus employs what can be seen as a principle of parsimony that it applies not to a single theory, but to the comparison of theories. Falsification, on this view, takes place in terms of one theory with respect to another and not to an individual theory by itself, and the result is that falsification in the sense of the naive falsificationism is neither sufficient nor necessary by itself for the elimination (or falsification) of a theory according to sophisticated falsificationism. A theory is not considered falsified under sophisticated falsificationism until there is a better one to replace it. The "refuting instance," in Lakatos's (1970) words,

becomes "the confirming instance of a new, better theory" (p. 122). More precisely, the sophisticated falsificationist regards a scientific theory T^1 falsified if and only if there is another theory T^2 that meets the following criteria:

1. T^2 must have additional or "excess" empirical content over T^1, namely, it must "predict" (that is used in the wide sense to include "postdiction") new facts improbable or forbidden according to T^1.
2. T^2 must subsume or account for all the unrefuted content of T^1.
3. At least some of the excess content claimed for T^2 must be corroborated.