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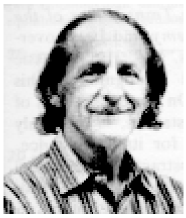

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The Metaphor-Science Connection

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In his *De Poetica*, Aristotle wrote that "the greatest thing by far is to be a master of metaphor. It is the one thing that cannot be learnt from others; it is also a sign of genius, since a good metaphor implies an intuitive perception of the similarity in dissimilars."[1]

By Aristotle's standards, few of us would qualify as "a master of metaphor." In fact, merely distinguishing the term "metaphor" from the related devices "analogy" and "simile" has been for me a source of some insecurity over the years. In spite of such insecurity, or perhaps because of it, the interrelationships between language, creativity, art, and science have always intrigued me. In two essays on the poetry-science connection,[2,3] for example, I discussed scientists who demonstrate uncommon skill with language and imagery in the verse they write. Metaphor, of course, is an essential component of poetic language.

My aim in this essay, however, is to examine some of the uses of metaphor in science and to provide a bibliographic survey of selected literature on the topic. As we shall see, metaphor enters into the communication of scientific ideas and at times influences the *formulation* of scientific problems and the ways in which problems are conceptualized and approached.

Thirty years ago in *Science* I proposed the creation of the *Science Citation Index*® (*SCI*®).[4] Were that paper to be republished now, I would argue that, among other things, the *SCI* is a tool for making and finding metaphors. A most important aspect of information retrieval is the ability to connect two separate, dissimilar events that indexes cannot show as being related—or, as Aristotle put it, to perceive the "similarity in dissimilars." Indexes not only facilitate information recovery but sometimes stimulate information *discovery* as well. An apt description was provided by Julian F. Smith, Department of Chemistry, Lenoir Rhyne College, Hickory, North Carolina, in a 1964 book review of the *SCI*. Smith described citation indexes as "systematic serendipity."[5]

Perhaps one of the most consequential encounters of my life took place in 1953 when William C. Adair introduced me to the legal decision citator known as *Shepard's Citations*.[6] This index to literature on legal cases facilitates detailed searching by listing the citations to precedents in federal and state courts and other administrative agencies. *Shepard's Citations* and the legal doctrine known as *stare decisis* (which deals with the importance of following precedents established by previous cases) served as major inspirations for the *SCI*. I became convinced that, just as *Shepard's* uses case citations to provide access to legal literature, a comprehensive index to the scientific literature could also be developed using references cited in scholarly articles. What I was doing, in effect, was drawing an analogy between previously unconnected parts of our culture: legal precedent on the one hand and the progression of scientific research on the other. In 1954, as associate editor, *American Documentation*, I asked Adair to write an article on citation indexes for scientific literature.[7]

As W.H. Leatherdale, University of New South Wales, Australia, writes in *The Role of Analogy, Model and Metaphor in Science*, one can find examples of metaphor "thickly strewn along the advancing path of science." The scientific employment of metaphor, according to Leatherdale, has occasionally led to "turning points in the history of individual sciences, great strokes of synthesis which provide a whole new basis for scientific advance."[8]

Definitions

In his book *Metaphor*, Terence Hawkes, University College, Cardiff, UK, reminds us that the word *metaphor* comes from the Greek *metaphora*, which derives from *meta*, meaning "over," and *pherein*, meaning "to carry." The term "refers to a particular set of linguistic processes whereby aspects of one object are 'carried over' or transferred to another object, so that the second object is spoken of as if it were the first."[9] (p. 1) Simple examples include "the brain is a computer," "the human body is a machine," or "man is a wolf." A related device, the simile, also involves this transference of aspects between objects but usually employs the terms "like" or "as" to emphasize the transference. The simile, in other words, involves an explicit comparison, in contrast to the implicit comparison evoked by a metaphor. Hawkes observes that the simile ordinarily involves a more visually inclined comparison between elements than does the metaphor.[9] (p. 3) Another related linguistic and analytical device is the analogy, which, according to *Webster's*, is a "resemblance in some particulars between things [that are] otherwise unlike."[10] Or, as the *Oxford English Dictionary* puts it, analogy is "presumptive reasoning based upon the assumption that if things have some similar attributes, their other attributes will be similar."[11]

Max Black, Department of Philosophy, Cornell University, Ithaca, New York, has written extensively about metaphor. In *Models and Metaphors* he notes that a metaphorical statement has two distinct subjects: a "principal" subject and a "subsidiary" one.[12] (p. 44) In the statement "man is a wolf," for example, "man" is the principal subject and "wolf" the subsidiary. Black has formulated what he calls the *interaction view* of metaphor, which centers on the interaction of these two subjects. In this view, the metaphor functions by applying to the principal subject a "system of associated commonplaces" characteristic of the subsidiary subject. These commonplaces need not be truthful or accurate, according to Black. The important thing for the metaphor's effectiveness is that the commonplaces be "readily and freely evoked."[12] (p. 40) A metaphor "selects, emphasizes, suppresses, and organizes features of the principal subject by implying statements about it that normally apply to the subsidiary subject."[12] (p. 44) Black's book has been widely read; over 400 publications cited *Models and Metaphors* in the *SCI*, *Arts & Humanities Citation Index*™ (*A&HCI*™), and the *Social Sciences Citation Index*® (*SSCI*®). As such, this work is a *Citation Classic*®.

Metaphor and Discovery

In *The Myth of Metaphor*, Colin Murray Turbayne, Department of Philosophy, University of Rochester, New York, writes that "the invention of a metaphor full of illustrative power is the achievement of genius. It is to create by saying 'no' to the old associations, the things that have constantly gone together, the things already sorted, and 'yes' to new associations by crossing old sorts to make new ones."[13] This 1970 book has also been widely read and has received about 100 citations.

In an article published in *Science* about 75 years ago, D. Fraser Harris, Dalhousie University, Halifax, Canada, cited several classic examples of metaphor in science. The English physician William Harvey (1578-1657), for example, evoked a metaphor when he speculated that the movement of blood in the body constituted "motion, as it were, in a circle." This concept, as Harris notes, was essential in the development of the science of physiology. As we know, shortly before his death and more than 30 years after Harvey introduced his revolutionary ideas about the circulation of the blood, that metaphor was demonstrated to be correct. What seemed only metaphor had, in effect, become reality.[14]

Similarly, as mentioned in my recent essay on meditation,[15] the chemist August Kekulé had his well-known dream in which a snake was biting its own tail. This circular image led him to conceptualize the arrangement of atoms in the benzene ring, soon to become a familiar chemical structure.

Michael T. Ghiselin, Bodega Marine Laboratory, University of California, Bodega Bay, discusses the metaphor-science connection in *New Literary History*. He maintains that metaphor played a substantial role in both the formulation and the communication of Charles Darwin's ideas.[16] A book on classical economics by Thomas Robert Malthus (1766-1834), *An Essay on the Principle of Population*,[17] provided Darwin with the insight to develop his theories on competition in the natural world. The idea of "natural selection" is based on similar thinking: just as domesticated plants and animals are altered through selective breeding, Darwin came to think, a comparable process occurs in the wild, with the environment determining which organisms will survive and reproduce. In explaining his theories on variation and evolution, Darwin employed a metaphor involving a "tree of descent." This was a significant departure from the "ladder of life" metaphor adopted by earlier theorists. They had generally represented life as a single, unbroken chain of organisms from the lower to the higher forms of life. Darwin's representation showed a branching diagram indicating gradual diversification among numerous independent lineages.[18]

Interesting historical examples of metaphoric description abound in psychiatry. Harvey Nash, Illinois State Psychiatric Institute, Chicago, in his paper "Freud and metaphor," notes that Freud "not only illustrated by metaphor, he also conceived by metaphor.... Often more than mere didactic or literary devices, Freud's metaphors played an important role in stimulating and guiding his thoughts."[19] One idea that had considerable influence on Freud's thinking was the metaphor of "fluid flow." Freud discussed trauma, for example, in terms of a flooding of the psychic apparatus by stimuli. Similarly, libido was described as a flow requiring regulation through displacement or damming. And the restoration of an ego damaged by neurosis was compared to the reclamation of flooded lands.[19]

The Harvard physicist and historian of science Gerald Holton, in his essay "Metaphors in science and education," cites a passage from an unpublished 1919 paper by Albert Einstein as his favorite example of "metaphor in the nascent phase of the scientific imagination." Einstein is describing an idea that had occurred to him a dozen years earlier. This idea, conceived in terms of a metaphor, would open the way from special to general relativity. Einstein observed: "As with the electric field produced by electro-magnetic induction [1905], the gravitational field has only a relative existence. For if one considers an observer in free fall, e.g., from the roof of a house, there exists during his fall no gravitational field—at least not in his immediate vicinity."[20] Holton observes that this "metaphoric transference," between the electric and magnetic fields on the one hand and the gravitational field on the other, led eventually to a "restructuring of our world picture."[21]

"The very nature of science," notes Earl R. MacCormac, Department of Philosophy, Davidson College, North Carolina, in *Metaphor and Myth in Science and Religion*, "is such that scientists need the metaphor as a bridge between old and new theories."[22] Richard Boyd, Department of Philosophy, Cornell University, Ithaca, New York, notes that "the use of metaphor is one of many devices available to the scientific community to accomplish the task of accommodation of language to the causal structure of the world."[23]

A similar thought is expressed by Thomas S. Kuhn, Department of Philosophy, Massachusetts Institute of Technology, Cambridge, author of *The Structure of Scientific Revolutions*.[24] "Metaphor plays an essential role in establishing a link between scientific language and the world. Those links are not, however, given once and for all. Theory change, in particular, is accompanied by a change in some of the relevant metaphors and in the corresponding parts of the network of similarities through which terms attach to nature."[25]

Holton has also remarked on the tendency of scientific imagery and vocabulary to shift over time. He notes that metaphors applied to physical science—metaphors that had predominantly involved themes of hierarchy, continuity, and order prior to the turn of the century—have in many cases been replaced by images of disintegration and violence. Examples include such terms as "particle annihilation" and "nuclear disintegration." This shift in imagery, according to Holton, may reflect "the characteristic style of our turbulent age."[21]

Nancy Leys Stepan, Department of History, Columbia University, New York, examines an analogy that was prevalent in many of the misdirected, racist theories on human variation that were propagated in the nineteenth and early twentieth centuries. This analogy linked race to gender. Using brain weight and other physical measurements and characteristics, scientists attempted to compare the supposedly inferior intellectual capacities of women with those of the so-called "lower races." Stepan uses this race-gender analogy to examine in broader terms the nature of analogical and metaphorical reasoning in science.[26]

Metaphors Describing Science

Metaphors have also been used to describe various facets of the scientific process. For example, Baruch S. Blumberg, Fox Chase Cancer Center, Philadelphia, and Renée C. Fox, Department of Sociology, University of Pennsylvania, Philadelphia, discuss the myth of Daedalus as a metaphor for the problem-solving and problem-creating aspects of scientific life. Daedalus, the legendary architect and inventor, found that each time he answered a question or solved a problem, other questions and problems would arise as a consequence. As Blumberg and Fox point out, scientists still recognize this infinite quality of scientific research, whereby answers usually lead to still more questions. The authors focus their discussion on ethical questions that have been raised as a result of research into hepatitis B, particularly in relation to screening and identifying people who carry the causative virus.[27]

The Daedalus metaphor is not unlike my own theory about the potential economic consequences of the knowledge-based society. Whereas traditional production of commodities may result in products that cannot be consumed, the production of new knowledge offers an advantage: knowledge as a commodity is perishable, in the sense that it may be replaced by newer knowledge, even while it may also be permanently useful or interesting.[28]

Daryl E. Chubin, contributing editor, *BioScience*, discusses another metaphor applied to scientific research: the notion that science is a national investment. Among the issues raised by this metaphor, as Chubin notes, is the problem of determining priorities in the allocation of limited research funds—deciding, in effect, where to invest. Another problem is evaluating the benefits, or dividends, that derive from basic research. He suggests that international cooperation in science—in facilities and research outputs—blurs national boundaries as well as national investment decisions. Therefore, in Chubin's view, science may be outgrowing this investment metaphor.[29]

Metaphors also provide a means for popularizing science. For example, in a 1959 series of lectures on human biology, Peter B. Medawar, Department of Zoology, University College, London, discussed the effects of stimuli on an organism in terms of an analogy that stressed the difference between a jukebox and a record player. This analogy helped to explain his distinction between *elective* and *instructive* stimuli.[30]

Of course, the use of metaphor in science has not been universally favored. Holton points out that the scientific application of metaphors has "tended to be an embarrassment to some scientists and philosophers." Francis Bacon, he notes, perceived some use for metaphors but generally dismissed them as serving people's natural penchant for fantasy.[21] Three hundred years later, the appropriateness of using metaphor in scholarly discourse is still under discussion. In a 1963 paper in the *Review of Metaphysics*, Douglas Berggren, Yale University, considered some of the abuses of metaphor. He mentioned the danger that "a given metaphor or its allegorical extension may be transformed into a myth."[31] This occurs when the differences between the metaphor's principal and subsidiary subjects become lost and the metaphor is taken literally.

Owsei Temkin of the Institute for the History of Medicine, Johns Hopkins University, Baltimore, Maryland, whose lectures I used to attend in the early 1950s at the Welch Medical Library, had much to say about metaphors in human biology.[32] He noted that although metaphors are considered appropriate for casual or poetic expression, "we expect the biologists to keep aloof from metaphorical concepts. Thereby, however, we underrate the power of the metaphor. I believe that metaphors have exercised considerable influence over biologists' thought."[32]

Boyd, examining the potential drawbacks of using metaphor in science, concludes that metaphors are appropriate as "constituents of scientific theories" so long as their use is governed by realistic standards of precision. Metaphors, he observes, should be employed only when there is good evidence that an important similarity or analogy exists between the two elements being compared.[23]

In a paper on metaphor and social perception, Scott F. Gilbert, Department of Biology, Swarthmore College, Pennsylvania, examines imagery dealing with diseases of the body politic. He discusses political metaphors in which foreign ideologies are depicted as external, infectious contagions. The rhetoric of the Cold War, for example, warned against the dangers of foreign "infiltration." Now that cancer has replaced infection as the chief medical worry of our age, political imagery now tends to speak of *internal* threats, usually depicted in terms of a growing cancer.[33]

Gilbert, with Jason P. Greenberg, medical student, Pennsylvania State

Table 1: Selected bibliography of books and articles on metaphor and science.

Boswell D A. Metaphor and observation in science. *Psychol. Rec.* 31:25-8, 1981.
Davidson D. What metaphors mean. *Crit. Inq.* 5:31-47, 1978.
Deutsch K W. Mechanism, organism, and society: some models in natural and social science. *Phil. Sci.* 18:230-52, 1951.
Farber E. Chemical discoveries by means of analogies. *ISIS* 41:20-6, 1950.
Gerschenkron A. Figures of speech in social sciences. *Proc. Amer. Phil. Soc.* 118:431-48, 1974.
Haraway D J. *Crystals, fabrics, and fields: metaphors of organicism in twentieth-century developmental biology.* New Haven, CT: Yale University Press, 1976. 231 p.
Hoffman R R. On metaphors, myths, and mind. *Psychol. Rec.* 29:175-8, 1979.
Jones R S. *Physics as metaphor.* Minneapolis, MN: University of Minnesota Press, 1982. 254 p.
Lakoff G & Johnson M. *Metaphors we live by.* Chicago: University of Chicago Press, 1980. 242 p.
Olson R, ed. *Science as metaphor.* Belmont, CA: Wadsworth, 1971. 321 p.
Orient J M. The medical metaphor for nuclear warfare: a critique. *Perspect. Biol. Med.* 27:289-98, 1984.
Ortony A. Beyond literal similarity. *Psychol. Rev.* 86:161-80, 1979.
Rothbart D. The semantics of metaphor and the structure of science. *Phil. Sci.* 51:595-615, 1984.
Schlanger J E. Metaphor and invention. *Diogenes* 69(21):12-27, 1970.
Shibles W A. *Metaphor: an annotated bibliography and history.* Whitewater, WI: Language Press, 1971. 414 p.
Sontag S. *Illness as metaphor.* New York: Random House, 1979. 85 p.
Sutton C. Metaphorical imagery: a means of coping with complex and unfamiliar information in science. *Durham Newcastle Res. Rev.* 9:216-22, 1981.

University College of Medicine, Hershey, has also written about the "lock-and-key" principle of chemical stereocomplementarity, a metaphorical concept that can be traced back to Louis Pasteur and Emil Fischer.[34] But it is Gilbert's paper on scientific puns that reminds me of our activities at ISI®. "Punning," he writes, "is the destruction of categories that separate one word or concept from another."[35] It strikes me that one might draw a comparison between punning and citation indexing. As I said earlier, the linking of two widely disparate concepts, through citation indexes, is one of the most fascinating aspects of information retrieval. It is also the most difficult to measure or evaluate. I am still waiting for the dissertation that measures the precision, relevance, or recall values of citation-based searches. The problem, in other words, lies in evaluating the *associations*, previously unknown, that are generated by the citation search. In this case, relevance, like beauty, is very much in the eye of the beholder. By far the most interesting papers I've retrieved from ISI's *Automatic Subject Citation Alert* (*ASCA*®) or the *SCI* are the ones that word searching would miss.

Scientific Maps as Metaphors

Other aspects of our work at ISI involve metaphor. We use citation analysis to draw up "maps" showing the relationships between clusters of papers or research fronts. These maps can be joined together into a comprehensive "atlas" of scientific research. The idea of maps representing knowledge, of course, predates ISI. In a discussion of scientific mapping that appeared recently in the *Journal of Information Science* (which we'll be reprinting shortly in *Current Contents*®), my colleague Henry Small and I mention some of the theorists whose ideas foreshadowed the use of maps to represent scientific knowledge.[36] The British bibliographer Samuel C. Bradford, for example, wrote in 1948 about a system of points and lines that would result in "a picture of the universe of discourse as a globe, on which are scattered in promiscuous confusion the mutually related, separate things we see or think about."[37]

Derek de Solla Price also wrote extensively on the idea of representing knowledge as a map. One of his concepts, for example, was an "operations room map" representing all scientific and technical knowledge, on which breakthroughs and advances in various areas could be signaled by flashing lights.[38] The metaphorical nature of scientific maps is also considered by M. Kochen and J. Lansing, Mental Health Research Institute, University of Michigan, Ann Arbor.[39] Writing in the special 1985 issue of *Scientometrics* that honored Price, Kochen and Lansing discuss the role of the periodic table in guiding the discovery of elements.

The early history of cartography, as discussed by Daniel J. Boorstin, Librarian of Congress, Washington, DC, in his book *The Discoverers*,[40] provides a metaphor for this scientific mapping. Just as the cartographers of the fourteenth century employed the accumulated knowledge and experience of sailors and travelers in constructing their maps of the world, so do information scientists gather and organize knowledge into maps and charts representing "worlds" of what we know. And, as wider exploration and greater technical sophistication throughout history changed our view of the world and its land and sea areas, so do advances and alterations in the course of scientific research change the way knowledge is represented.

In Table 1 we present a selected bibliography of titles pertinent to metaphor and science, in addition to those sources explicitly cited in this essay. Table 2 lists some of the main journals that have published research on this topic.

This essay alludes only briefly to the usual citation details of the works involved. To construct a proper map of the research front relevant to this topic we need to cluster at least a 10- or 20-year file of the entire ISI database. The subject spans the world of the *A&HCI*, *SSCI*, and *SCI*. What is fascinating about this "small" field is that its core works are well cited in the literature of all three indexes—certainly out of proportion to the number of scholars who work in it. Those who fund scientific research should consider carefully the implications of such connections.

In her book *Models and Analogies in Science*, Mary B. Hesse, Department of History and Philosophy of Science, Cambridge University, offers this thought: "Rationality consists [of] the continuous adaptation of our language to our continually expanding world, and metaphor is one of the chief means by which this is accomplished."[41] As the world continues to expand through scientific research, metaphor will no doubt endure as an integral part of scientific cognition and communication.

Table 2: A selected list of journals that publish research on metaphor and science. A = title and first year of publication. B = 1985 impact factor.

A	B
Cognitive Psychology—1970	3.18
Daedalus—1958	0.37
ISIS—1912	0.82
Journal of Psycholinguistic Research—1971	0.40
Philosophy of Science—1934	0.50
Psychological Record—1937	0.47

See next page for list of references cited in this essay.

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