INTRODUCTION

To some scientists and philosophers, metaphorical theories are preposterous: "That theory's for the birds—it's just a metaphor." And yet, a point is often reached in scientific theorizing where scientists are stuck with little but fantasies, hunches, free associations "couched in figures of speech, metaphors, etc. We may begin as a poet talks rather than as a scientist is supposed to talk." Here, Abraham Maslow (1969, p. 129) describes some root mental machinations of scientists. Maslow, Kuhn (1965), and others throughout the history of science have described the roles of psychological factors in the scientific enterprise. But how do scientists who are steeped in metaphor tell when they are on the right track? More specifically, how can a metaphor have scientific utility? How can it mislead?

This chapter begins with summaries of the views of some philosophers and scientists—pro and con—about the status and use of metaphors in scientific theories. Following this is an examination of some specific scientific metaphors, their character and foibles, which leads here to an attempt at a description of the place of a metaphor in a theory. The discussion involves some ideas about how to assess metaphorical theories. Much of the literature on this topic is from the philosophy of science, a discipline populated by an inordinate number of physicists. This chapter uses example metaphors from many sciences, especially psychology (The mind is a computer), but it also relies on some well-worn examples from physics (An atom is a solar system).
ATTITUDES ABOUT METAPHOR IN THE PHILOSOPHY OF SCIENCE

Attitudes Con

Some in philosophy of science and in the philosophy of psychology feel that metaphor is no good when used in a theory (e.g., Carnap, 1959; Hemple, 1965; Turbayne, 1962). They rule out metaphor as legitimate in science as a consequence of the positivistic attitude: Scientific explanation, it is claimed, consists of the use of logical generalization, laws, and literal deductive relations between the theory language (of concepts or constructs) and the observation language (or behavioral language) of operational definitions (Bergmann, 1940; Bergmann & Spence, 1941). By this view, a metaphorical theory is at best a possibly heuristic I.O.U. At worst it is an irreal fungus doomed eternally to a prescientific twilight zone. Any good, rigorous theory should be literal and precise (Boyd, 1979; Pylyshyn, 1979; Royce, 1978; Ryle, 1949). Bergmann (1940, p. 422) gave this specific critique of the Lewinian (introspectionistic) "field" theories of the 1940s: "what is the predictive value of the suggestive metaphor, "psychological environment"? Is it not the business of science to ascertain which objective factors in the past and present state of the organism and its environment account for the difference in response?" Psychologists MacCorquodale and Meehl (1957) also prefer literal theories—those with intervening stimulus and response variables—to theories with anthropomorphic or metaphorical hypothetical constructs. The literal properties involved in hypothetical constructs are said to be the properties that matter for the theory anyway: metaphors are so much excess baggage or "surplus meaning." The Zeitgeist from about 1920 to about 1955 involved a somewhat compulsive semantics. Theories were said to rely on the formal logic of postulates, propositions, and curve-fitting, and not on the content of the propositions (Carnap, 1937; McGuigan, 1953; Woodrow, 1942). Theories were supposed to avoid all the vulgarities, ambiguities, mentalisms, and vaguenesses of ordinary language (George, 1953; Kantor, 1941; Kattsoff, 1939; Maatsch & Behan, 1953; Rokeach & Bartley, 1958; Rozeboom, 1956; Spiker & McCandless, 1954). The meaning of theoretical terms was to be given only by operational definitions—this was what was supposed to make theories testable (Bridgman, 1927; Kantor, 1938; Stevens, 1935). Rapoport (1935) admonished theorist to tolerate metaphor with an attitude of "linguistic hygienics"—one should be constantly on guard against metaphors. As Max Black put it (1962), some philosophers of science proclaimed, "Thou shalt not commit metaphor!" Black's own philosophy is more liberal. But even then he tells scientists to use many metaphors, if any are used at all, so that our favorite metaphors do not lead us astray!

It is one thing to be sensitive to the metaphoricalness of a theory—as a possible pratfall or tool—and quite another thing to reject a theory because it is a metaphor.
Attitudes Pro

In contrast to the logical positivists’ campaign for a theory devoid of metaphor and ambiguity, some in philosophy have attributed to metaphor an important role in scientific theorizing (e.g., Hornsburgh, 1958). Indeed, it has been the expressed goal of some in philosophy to show how the psychological aspects of metaphor use (e.g., word-meaning change, cultural effects, context effects, novelty) make the logical positivistic approach untenable. On the basis of the psychological aspects, Beardsley (1962), McCloskey (1964), Mooij (1975), and Nemetz (1958) asserted that the “logic” of metaphor is beyond the grasp of any exclusively philosophical analysis. To cite one specific argument, Berggren (1963) pointed out that any scientific explanation, though ostensibly a logical deduction, can nonetheless rely on metaphor, since metaphors may creep into the premises of the deduction from somewhere else in the theory!

To summarize, some in philosophy of science maintain that scientific explanation should be a purely logical-rational affair. Hence, to them, ordinary language, including metaphor, is a bad vehicle for stating theories. Others assert that since metaphors are used in science and in ordinary language, and since the “logic” of metaphor is not obviously rational, then the search for a purely logical-rational basis for science may be misguided.¹

SCIENTISTS’ ATTITUDES ABOUT THEIR METAPHORS

Attitudes Con

Some scientists are critical of the use of metaphor in theories. Here’s a sampling. Some physicists objected to the use of metaphor in their discipline—Mach, Sir Oliver Lodge, and, in particular, Rene Duham (1906) (see Gregory, 1931). To linguist Noam Chomsky (1965, Chapter 1), at least one theory, the associationist-habit view, in only a metaphor and is misleading for what it disguises. Psychologist Weimer (1973) prefers a nonmetaphorical description of the evolutionary survival value of knowledge over a teleological description that is said to be “at best” a metaphor—as if metaphoricalness were somehow to blame. Other social scientists claim that metaphor has only pedagogic value. It is

¹The doctrines involved in operationism and logical positivism also had critics who did not focus on metaphor per se, but on the notion that theories need concepts from ordinary language in general. Some expressed the need in philosophy for “nonstrict” or tacit modes of inference or judgment (Hall, 1942; Polanyi, 1968; Scriven, 1962). Some expressed the need for meaningful ways of relating operational definitions (Bentley, 1937; Bills, 1938; Israel & Goldstein, 1944; Maze, 1954; Suppe, 1973). Some pointed out the failure of operationists to obtain the precision they claimed they could obtain (Chomsky, 1959; Polanyi, 1958). Physicist Bridgman (1936) was himself convinced to alter his initial operationistic philosophy (1927; see Lambley, 1970). The history of operationism and logical positivism from the perspective of psychology is reviewed in Leahey (1977), Meissner (1960), Rocheboom (1956), and Stevens (1939).
said that metaphor serves as a shorthand mnemonic device for remembering or explaining ideas, and not as a valid medium for creating or inference-making (Deese, 1972; Green, 1979; R. Miller, 1976). In Arbib’s (1972) treatise on the “computer model of the mind,” he is explicit about the metaphor involved and hopes that it will be refined and its false importations will be discarded—so that the metaphorical aspects can be ignored (p. 11). In a paper on issues involved with psychological theories of memory representations, Palmer (1978) argues that the important aspect of representations is the preservation of information as in information theory metrics. In this way, he seems to rule out metaphor and other semantic aspects of cognitive theories.

On the main, however, most scientists seem to have a favorable attitude toward the use of metaphor. This may be related to the simple fact that metaphors abound in science.

Attitudes Pro

First, consider physics. James Clerk Maxwell and William Thomson (Lord Kelvin) explicitly acknowledged their metaphors—the “lines of force” notion of magnetism, the concept of a “dance of molecules,” and the idea that heat is a “fluid.” To Maxwell, the creative scientific mind does not seek some sort of thermodynamic equilibrium or quiescence, the mind is a “tree shooting out branches which adapt themselves to new aspects of the sky toward which they climb.” The progress of science cannot be predicted or anticipated by logic (Maxwell, 1890, p. 226). Maxwell encouraged the use of diverse forms of thought, including imagery, mathematics, drawings, models, and metaphors. He was quite explicit on this—metaphors are not only “legitimate products of science, but capable of generating science in turn” (1890, p. 227). Another fascinating theorist was Michael Faraday—at almost every turn he relied on metaphor. For electrical conduction to occur, he reasoned, either the particles must touch and have volume, or the particles might be pointlike centers of force with “atmospheres” of energy. The latter case suggests that matter is

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\frac{1}{dp} = \frac{dt}
\]

Maxwell’s mathematics were mind-boggling. But his papers and lectures relied also on poems from Milton, on drawings, and on illustrative images and metaphors—to generate as well as explain the math. It may seem ironic that physics is touted as the most precise and mature science and yet physicists themselves are usually very playful and flexible in their creativity.
everywhere continuous—leading Faraday to the notions of a "field" theory, and an "elastic" fluid. Faraday, who used little in the way of math, thirsted for metaphors and images, such as the use of iron filings to show the magnetic "lines of force." Philosopher Mary Hesse (1962) found that she could use metaphors as a means of analyzing the history of physics, including a demonstration of trends in attitudes about the use of metaphors and models.

In a broader psychological context of science, general problem-solving, many treatments of problem-solving strategies describe the use of metaphor in the creation of solutions (e.g., Gordon, 1961; Schon, 1979). A favorite example is the invention of the plastic twist-top that turns to open and close for dispensing sticky substances like glue. Its action makes it self-cleaning. The metaphor used in the generation of this device was that of a horse's rectum.

The utility of metaphor has been recognized by rhetoricians and linguists who have analyzed discourse and communication (Culler, 1975; Stelzer, 1965). Discourse can be described in terms of the military metaphor of attack and defense. The philosophical world view called Mechanism was instantiated in Hume's metaphor of speech as a set of tools and Herbert Spencer's metaphor of speech as a set of symbols arranged in a machinelike manner, still current notions. By Reddy's (1979) estimation, well over half of the terms used to describe communication are metaphors. Words are said to contain and transfer thoughts, ideas, meanings, or feelings. Thus, the listener's task is to extract the meaning from the words. Meanings can come across or pour out. They can be captured, loaded, forced, pregnant, hollow, empty, buried, exposed, lost, and so on. Indeed, language seems to prefer metaphors for facilitating communication about communication (theories are maps!).

Nemetz (1958) went one step further. His claim was that theories of metaphor must also be metaphorical. Consider Plato's metaphor of the "fabric of discourse," or "woven ideas." The modern manifestation of this is the "tension" theory of metaphor: A metaphor is deviant or anomalous and recognition of the anomaly induces a tension that needs to be resolved through the process of interpretation or assimilation (Beardsley, 1962; Osborn & Ehninger, 1962; Perrine, 1971). Metaphor has also been likened to a filter or selection of characteristics (Black, 1962; Hesse, 1966; Richards, 1936), an idea that shows up as the semantic feature transfer view of metaphor meaning. According to rules, features are transferred or transformed.

Psychology also makes much use of metaphor. This couch reeks of verbosity is an item from the Harvard Anal Disposition Scale (Couch & Keniston, 1960). Psychodynamically oriented writers have, since Freud (1905), considered nonliteral meanings to be special—not only in terms of the insights metaphors give into the patient's deepest thoughts and motivations, but also as a medium for theorizing. The ego is a helmsman, libidinal drives are energy, striving is a flow, and attitudes are a river bed (Nash, 1962). As a part of the theory of psychoanalysis, since metaphor is a basic mechanism for the expression of subliminal drives, so
too is it a means of analyzing the drives. Jung’s elaborate system of “archetypes” is a set of metaphors tailored to unpack culturally rich symbols and allusions. The archetypes are meaningful themes that describe the unconscious as it is manifested in tribal lore, sculpture, religious myths, fairy tales, and neuroses. Two such archetypical symbols are the Mother—spirit mother, earth mother, sympathy, fate, passion, depth, receptivity; and the Trickster—representative of saint, fool, divine, animal, innocence, childhoodness (see Jung, 1969).

One can wonder with Edie (1963), Roediger (1978), Paivio (1974), and Snell (1960) if there is any literal term for thoughts, memories, and mental images (see also Turbayne’s analysis of the picture or camera metaphor for vision, 1962). Cognitive terms cluster into themes: Greek metaphors for seeing—theory, idea, intuition, reflect, focus, introspect, outlook, perspective, recognize; Latin metaphors (somewhat more obscure) from agriculture—recollect, comprehend, observe; and both Latin and Greek metaphors for sex—intercourse, conception, impression. From these possibly illicit parents spring modern memory metaphors. A mind is closed, open, narrow, a switchboard, a wax tablet, a garbage can, a tuning fork, a lock and key, and of course it is “filled” with vivid picture-images that “firmly tie” the memories together. Such metaphors indicate the attitudes and philosophies adopted by entire language cultures. They are to Breal (1887) a museum of language and to Edie (1963) an etymological storehouse of previous ponderings. In effect, we cannot avoid either our history or our metaphors.

Metaphor, it seems, can be and perhaps must be brought to bear on whatever problem scientists may be grappling with.

THE STATE OF THE ART IN PHILOSOPHICAL CRITICISM

Granting for now that metaphors do play a helpful role, how do they work? The few ideas presented by those who have done some analysis on this point can be boiled down to two notions: (1) Metaphor can often result in new descriptions or in choices between theories (Boyd, 1979; Chapanis, 1961; Hesse, 1966; Rapoport, 1953), and (2) metaphor works in a theory like analogy works, but metaphor is analogy that is fancied-up by inference-making and resemblance-finding (Nagel, 1961; Nemetz, 1958). Most of the seminal works, like those of Black and Hesse on philosophy, focused on the problems of how to identify metaphors and of whether metaphors can be given literal paraphrases. Their noble goal was to get philosophers of science to admit metaphor as a legitimate description of aspects of science by showing how metaphor is important and by attempting some definitions. This, however, is not enough. If metaphor allows for special insights, then it does something a literal theory could not or might not do. If metaphor is so rich and communicative, then we might see all operational
definitions and careful descriptions give way to layers of gooey metaphors. The
Journal of Experimental Psychology might read more like Joyce than Spence. In
actuality, metaphors do not run quite so rampant. Even so, no specific criteria for
assessing a metaphorical theory have been offered. Nor has any explicit attempt
been made to represent the place of a metaphor within a theory. What if
metaphoricalness itself can be used to make some rational decisions about the
theory? Can we establish decision criteria for throwing out or keeping a
metaphorical theory based on the circumstances in which a metaphor will have
scientific utility? Such criteria would tell us what to look for in a metaphor and
what to look out for. Furthermore, how can we know if a decision criterion is a
good one? That is, how can it be known that a decision to throw out a metaphor,
on the basis of metaphoricalness, was a sound decision?

The next section is a step toward answering these questions—a skeletal (but
hopefully adequate) account of what metaphor can do that's bad for science and
what it can do that's good. From this I go into a more formal (but sufficiently
skeletal) description of how a metaphor might fit in with the network of predic-
ations and postulates that constitutes a theory.

**METAPHOR AND TRUTH, HIDE AND SEEK**

It is sometimes claimed that a scientific metaphor, being nonliteral, will always
hide the truth. Usually when this argument is made, the metaphor ends up being
used to disclose that which it supposedly hides. To say, Metaphors can hide, is
to be a victim of the very defense one is trying to overcome. As the following
examples show, metaphor can seem to hide truth in different ways, some more
remediable than others.

**Metaphor, Mass, Math, and Myth**

Sometimes metaphors seem to hide the truth, not because of metaphoricalness
but because of the use of metaphor in flabby theorizing. One can speak in physics
of elementary particles "feeling" a force without really committing a sin. The
domains of particles and (human) feelings are too disparate for this metaphorical
language to imply (to a physicist) a teleological or cause-effect relation. In
biology one can speak of cells "feeling" the effects of toxins. This is not a
scientific metaphor in that it is not strictly an attempt at explaining a concept in
biological theory or methodology. The term "feel" has no obvious counterpart
in biological theories of cell behavior (excepting observable reactions like
movement). "Feel" is a descriptive short-hand. Since cells and people are similar
domains, at least more similar than people and particles, the statement The
cells feel the toxin can suggest certain cause-effect or teleological relations—it
may hide the truth. The metaphor may give a false sense of understanding; im-
portant questions may go unasked. The classification that the metaphor implies may thus keep the experimenter (or student) from making distinctions that should be made. That is, the theory might need or require a number of concepts where the metaphor suggests only one . . . unless, of course, the experimenter recognizes the metaphor and uses it to get at what is "hidden."

An example of faulting a metaphor when it's really the theorizing that is to blame is Hinde's (1955) critique of Tinbergen's theory of instinct mechanisms. The ambiguous word "drive" is used by Tinbergen to refer to the biological causes of behavior, to the mechanism that connects the biological processes to behavior, and to the state of the organism when so motivated. A drive is sometimes said to flow and be discharged, sometimes it is called a fire that can be put out, sometimes drives are said to be fed or satisfied, sometimes drives are said to be generalized or thwarted. Certainly Tinbergen makes fast and easy use of a rich set of metaphors. To Hinde, this results in an ethological theory that is a cause-effect nightmare. The principles in the theory are confused; the theory has many implicit postulates of entities and dispositions; and the theory makes some claims that are false (i.e., that there is no role of feedback, that there is no role of consciousness). But the metaphors do not hide the truth—Hinde used the metaphors to disclose the implicit assumptions! It is Tinbergen's depth of theorizing that was insufficient.

It is claimed that another way in which metaphors hide the truth is by being pervasive and going unrecognized. In this way, metaphors are sometimes said to acquire the status of "myth" (Berggren, 1963; Hoffman, 1979). There are alleged instances of scientists "confusing" their metaphorical mechanical models with the theories that the models instantiate (Hempel, 1965, pp. 433-435). Physicist William Thomson is often cited as an example: "If I can make a mechanical model I can understand it" (1884, pp. 131-132). Far from being an unreasoned confusion, this was deliberate on his part, a matter of his philosophy of science. It may be improper to use the value-laden term, "myth," to label viewpoints that rely on metaphors and models in the construction of theories.

Metaphor can mess us up (simply enough) by suggesting an entity or property that is wrong. So much the worse for the theorist if the property or entity is somehow regarded as special. A good example of this is the physicists' penchant for using odd terms to talk about particles. The most elementary particles, called quarks, come in many varieties. Some have "color," some have "charm," some are "strange." Quarks seem inextricably bound together as if "tied by a string" or "contained in a bag," or so some theories of quarks describe it. One begins to wonder if leptons can sin and if baryons can die. Let me focus on the property called "spin." At the level of description in physical theory "particles" are not masses. They do not spin. But then, why use the word "spin" and where did its use arise? Spin is a property word used to describe the angular momentum of particles. Spin does not refer to motion as in a spinning top. Nothing actually rotates, or speeds up or slows down, for that matter. The property is fundamental
to the particle—change the spin and the particle has changed. Beams of particles can be magnetized, accelerated, collimated, and otherwise separated out into bunches of pure types. Observations show that some particles break up into two photons. One is labeled a "spin-up" photon, the other is labeled a "spin-down" photon. Otherwise, they are alike in the math. If it seems confusing, that's because it is. An elementary particle in quantum mechanics is not even a particle in the sense of being a spatially extended body. In this case, metaphorical language persists despite its falseness.

Metaphor and Verisimilitude

If pressed, scientists generally admit, Realist Hat in hand, that theories are not THE TRUTH, that theories are functional or "instrumentalist" fictions. It's not that the theory is WRONG. If it is, then some other theory should be doing the predicting. It's that theories are not entirely true. Metaphor certainly qualifies. But it is debatable on logical and philosophical grounds whether any theory can be TRUE (see Carnap, 1945; Nagel, 1961). For present purposes, the best we might say in order to get the discussion off the ground is that any theory (verbal, mathematical, metaphorical) is to some degree "truthlike" or has some verisimilitude (Popper, 1959). A falsified theory should not necessarily be abandoned, whether or not it contains metaphor. Theories without metaphor can need some simplifying auxiliary postulates ("all other things being equal..."), short-hand mathematical theorizing, temporary hypotheses, entities that are not "real," incompletenesses, phenomena or properties that are not "directly sensible," and the like. So it may be unwise to reject a theory (only) because aspects of its metaphoricalness may seemingly detract from its truthlikeness. Even what appear prima facie to be absurd metaphors may be useful. For instance, to suggest that concrete blocks are springs seems absurd. Yet, the behavior of concrete blocks subjected to brief stresses can be approximated by a mathematical instantiation of a spring model (see Feld, McNair, & Wilk, 1979).

Metaphor Could Rhyme with Popper

We might inquire as to what a good metaphor should do for its theory; what we might want it to do. At least, we would like it to do what any positively Popperian postulate should: generate falsifiers. A theoretical postulate, metaphor or not, should lead to demonstrations of how the theory needs modification of its assumptions or other "ad hocery." The phenomena in the universe of discourse

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3 For a description of the various versions of the philosophies of instrumentalism and realism in metatheoretics, with an eye toward the role of psychological factors (i.e., reference, perception, intelligibility), see G. Maxwell, 1970.

4 The concept of verisimilitude or degree of truth-likeness is problematic in philosophy (see D. Miller, 1976; Popper, 1976; Tichy, 1976), yet it continues to be a very useful concept.
can then be reexamined to see if they behave as the theory says they ought. Deviation from the predictions may show how to fancy-up the theory. As Hornsburgh (1958) stated, it should be possible to show how the metaphor is wrong in important respects. Indeed, it should be possible to show how the metaphor is wrong in exactly those respects that the scientist relies on to make the metaphor useful! In other words, a metaphor should show how to produce strong falsifiers of the theory: what the experimenter regards as strong predictions that would kill the theory if not borne out. In fact, an interesting dividend from metaphorical theories is that they make obvious some of the ways in which they are false. An example is the hydraulic pipes and fluids metaphor for the nervous system or for motivation and drives.

Lorenz postulates for each instinctive act, a particular ‘reaction specific energy’ which he pictures as accumulating in a reservoir with a spring-valve at its base. In an appropriate situation, the spring-valve is released partly by the hydrostatic pressure of the reservoir’s contents and partly by the action of the external stimulus, which is pictured as a weight on a scale pan pulling against the spring (Hinde, 1955, pp. 321–322).

The metaphor does account for facts, for instance the reduction of response strength following a reaction—the reservoir has been drained and a stronger stimulus is needed to evoke the response again. But this is, perhaps deservedly so, the whipping-post of scientific metaphors. It shouts, ‘I’m a metaphor!’ The question is not one of whether we can bring about observations that constitute falsifiers of the theory, but a question of when we should choose to use the obvious falsehoods in a criticism or refutation of the theory. Based on myriad factors of preference, we can choose to disbelieve the metaphor at any point.

The general rule some scientists and philosophers seem to follow, today as in the past, is this: If you don’t like a theory (or theorist) and if the theory is metaphorical or contains metaphor, you can usually get away with criticising the theory by saying, ‘It’s only a metaphor.’’ Often, however, this is a matter of attitudes and may have little or nothing to do with metaphoricalness. Ironically, the falsifiability of metaphors is why those who dislike metaphors may have been able to serve a helpful role—by focusing our attention on falsification. However, they would see metaphor as negative and scientific progress as degenerative. Metaphor can also be regarded as possibly constructive. Since any theory may be falsifiable and may have some verisimilitude, rejection of a theory or hypothesis because it is a metaphor may actually be based on a philosophical commitment to certain literal logical theories and unfortunately may not regard the creative role of metaphor at all.

Putting Metaphors “On Hold”

In order to be falsifiable or confirmable, a statement in a theory must at least be interpretable in terms of observations or empirical consequences. Other criteria
have been proposed, for example, that the empirical consequences also should not be entailed by other principles in the theory alone. However, the logic of falsification is debatable (see Ayer, 1959, versus Carnap, 1956, versus Hesse, 1962). The point here is that it is the fate of scientific metaphors to be modified as the theories change in light of evidence. The way the scientific community often treats metaphors is to “put them on hold”—to regard them as falsified but to use them creatively until such a time as when they might be thrown out altogether. This seems ironic, for many writers in the philosophy of science are careful to warn, often in an admonishing tone, that metaphors should not be too figurative, that is, misleading (e.g., Black, 1962, p. 225; Hinde, 1955). But scientists are not all suckers, they can be quite well aware of the differences between concepts given by the theories and concepts suggested by metaphors. The metaphors and theories are not “confused” but used to explore nature and to lead to modifications of principles.

The holographic model of memory may be taken as a good example of this, since debates about it have been well documented (see Arbib, 1972, Chapter 6; Pribram, 1971, Chapter 8). A mathematical instantiation of the holographic hypothesis makes predictions of associations on the basis of interference patterns and reference beams, but the “predictions” of associations (“ghost images”) are due largely to the power of the transformations allowed by the mathematics, and not to any model. The mathematics is Fourier analysis and wave mechanics. Any spatially localizable difference between two energies can be expressed as a wave or wave interference effect by changing the resolution or grain of the equations. In fact, the holographic hypothesis has infinite power—it “predicts” (allows for) too much.

One reason why the holographic hypothesis has been troubled by debate is because, it may be said, it is a multileveled or mixed metaphor. Mixing of metaphors occurs in science when a metaphor that is used to explain a theoretical concept refers in its vehicle term to a domain that has its own special explanatory physical theory and metaphor. The holographic hypothesis needs constraints based on psychological principles. Pribram (1971) tries to incorporate the holographic hypothesis into an information processing view. This serves the purpose of injecting psychological principles into the hypothesis, but it does so by making the metaphor mixed: The possible combinations of processing-holographing models in the eclecticism are legion. Philosopher Pepper (1942) anticipated the possibility of such eclectic metaphors. He said they would be confusing.

The notion that memories or associations act like holograms may be a powerful notion. We know that memories act like holograms in that no individuated memory seems to be “stored” in an individualizable neural locus—this is the phenomenon that led to the postulation of the holographic hypothesis in the first place. But this may be as far as the holographic hypothesis can go—it also does not work at another level—the level of its optical reference. A student once asked Pribram, “But doesn’t the laser process destroy brain cells?” (quoted in Arbib, 1972, p. 186). To use the hypothesis and satisfy the equations of wave mechanics
one must regard the nervous system as a neural lattice, associative net, or other
form of coherent medium. The angle of incidence is equal to the angle of
reflection. So what? Yet, at some time in the future a brain or conscious analog
may indeed be found for the hypothesis, for example in neuromagnetic waves or
electromagnetic graded potentials or something. It has been suggested that those
areas of the brain that have layers of interconnected neurons may be regarded as
if they generate "waves"—that is, graded electromagnetic potentials (Lashley,
Chow, & Semmes, 1951; Pribram, 1971, Chapter 8).

Arbib says that we can use the hypothesis now by not taking it "too literally." He
means is that we form a new version of the hypothesis: Memory is
conceived of as a dynamic analysis of psychologically relevant perceptual features,
with recall conceived of as a reconstructive process based on feedback.
Indeed, here Arbib has nearly eliminated the metaphor altogether! Pribram also is
clear on the limitations of the hypothesis (1971, pp. 63-66), and he too comes
close to modifying the metaphor out of existence. "The essence of the holo-
graphic concept is that images are reconstructed when representations in the form
of distributed information systems are properly engaged" (p. 152). As J. C.
Maxwell pointed out (1890, p. 301), as the incompleteness of a metaphor are
disclosed, the metaphor can be modified, perhaps to the point of generating a
literal hypothesis.

Metaphor and Verification

In contrast to the requirement of falsifiability and the attendant possibility of
modification of theories and metaphors, we might also require metaphors to be
verifiable. Ideally, metaphors should be verifiable in many ways. Just as aesthet-
ically rich metaphors can be given a variety of distinct interpretations, we should
be able to check out our scientific metaphors in a number of ways. The best case,
the scenario in which scientists have the most to gain, is the case in which we
know a little about the topic of the metaphor (the to-be-explained entities in
the theory) and a lot about the vehicle term. A good example comes from the
kinetic theory of gasses, which relied historically on the metaphor that likened
the particles of a gas to billiard balls that bounced off one another, thereby
generating heat and pressure. On the basis of assumptions of perfectly elastic
pointlike particles and a correspondence of temperature and kinetic energy one
can derive statements about gas diffusion rates and expansion rates and one can
derive the "ideal gas" laws—which real gases do not follow under all condi-
tions. Dutch physicist Van der Waals pursued the metaphor to refine the theory.
"Real" particles, he reasoned, do take up some volume. At the lower tempera-
tures their volume becomes considerable with respect to the paths taken by the
particles' motions. Hence, there are deviations from the ideal laws. As a part of
the bargain, from Van der Waals's equations one can also derive statements
about viscosity. Thus, in redefining the theoretical concept, a metaphor can have
an effect on the entire network of principles and concepts in the theory: It can add order and harmony.

**THE MANY FORMS OF SCIENTIFIC METAPHOR**

**The Rhetoric of Scientific Metaphors**

There is more than one way to involve a metaphor in a theory. Particular rhetorical forms of figures of speech can be identified with the roles served by metaphor: Metonymy involves attribute-whole and cause-effect relations: *Particles are billiard balls*. Synecdoche involves exchanges of elements within a classification system: *A person is a communications channel*. Oxymoron involves paradox and contradiction: *Particles are waves*. Perhaps a rhetorical analysis could be used by scientists to help generate metaphors tailor-made to the scientific task at hand!

In a *metaphor theme* (Black, 1962), the universe of discourse of the theory is compared *en masse* to some other domain. The mind/brain as a computer is an example of a metaphor theme. As Black saw it, and as philosopher Stephen Pepper foresaw it (1942), metaphor themes can be central to a world view or paradigm, almost a part of metaphysics (*Everything is water*). Pepper showed how metaphor themes are the basis of philosophical "world hypotheses" such as Mechanism, Atomism, and Organicism. Perhaps the existence of this global form of scientific metaphor is why some were led to equate metaphorizing with mythologizing. A metaphor theme, at least when expressed as a sentence, will obviously be too terse for use as an actual full-blown scientific theory. It is the more specific properties perceived by the experimenter that lead to the creation of hypotheses or principles. That is, a metaphor theme provides a bunch of related little metaphors, in which a concept or phenomenon in the theory is used as the topic in a metaphor. *Thoughts and brains work like computers work* is perhaps the most salient of psychological metaphor themes. It is *not* a way of making a vague generalization, but a way of introducing specifications or constraints on the definitions of theoretical concepts (e.g., *Short-term memory is a push-down stack*). The vagueness is only apparent and occurs as an epiphenomenon of the search for explanations rather than because of the use of metaphor. Uhr (1966, pp. 366–367) wondered what was meant by the plethora of terms that were being taken from the language of information processing and applied to the description of human memory and pattern recognition, terms such as trace, reconstruction, transformation, operation, mapping, and the like. But compare this criticism, that is, that the computer model is in one way or another vague (cf. Drescher & Hornstein, 1976; Dreyfus, 1972; Moor, 1978), to recent treatments of the complexities in the philosophy of artificial intelligence (Haugeland, 1978; Hunt, 1971; L. Miller, 1978; Pylyshyn, 1978). Here are some of the specific issues: (1)
How do types of computer memory correspond with types of human memory? Do computers represent information and meaning in ways like people do? (2) How do the types of computer message analysis (parsing routines) correspond with how people parse messages? (3) How can computers show intention or will? (4) How would computer subroutines correspond with brain structures? Can psychological functions be "carved up" spatially as they are in computers? (5) Should a human capability be programmed by "brute forcing" information into memory or should the capability be represented by strategies and programs that modify themselves? Psychologists have also benefited from the metaphor. The information processing language is precise and powerful. Distinctions such as between encoding, storage, and retrieval have for some time been used to extend cognitive-learning theory and to lead to new experiments (cf. Anderson & Bower, 1972). In short, there is as much detail derivable from the metaphor theme as the analyst cares to look for.

Indeed, this can be taken a step further. It may be possible to analyze and classify information processing models, mental representations, and even syntactical or propositional representations according to their manner of metaphorical expression of time, process and structure.

Image, Metaphor, Model, and Theory

Galleons of scholars describe an important role of mental imagery in scientific metaphors (Asch, 1958; Deese, 1972; Kuhn, 1979; McCloskey, 1964; Paivio, 1979; Steenburgh, 1965; Vico, 1948; and others). They describe metaphors as namings based on a salient image or powerful perceptual resemblance that can somehow take precedence over a theory that may be more abstract or elaborate. Thus, metaphor may be inevitable and necessary to science, and cognitively prior to scientific description, because of psychological factors in learning, inference-making, symbol-formation, and explanation (Hester, 1967; Langer, 1957; Pollio, Barlow, Fine, & Pollio, 1977; Ortony, 1975; Schon, 1963). Einstein's images of riding a beam of light and other Gedanken experiments, as they were later called, were essential to and psychologically prior to the mathematical laws that so influenced physics. In fact, Einstein himself created a flow diagram representing the process of creative thought, including places for imagery and intuition (see Greenberg, 1979). An examination of the vehicle terms used in scientific metaphors supports the claim that images are important. It seems as if anything concrete goes—pinwheels, elevators, pumps, apples, paper bags, pianos, garbage cans, bullets, funnels, maps, puzzles, snakes, playing cards, etc. (see Dreistadt, 1968). Available analyses of scientists' thinking, the questionnaire studies by Roe (1951) and Walkup (1965), show that scientists often report using mental imagery.

It should come as little surprise then, that metaphor is implicated in theoriz-
ing by what J. C. Maxwell called "physical analogy" and by what others called material analogy, picture theories, isomorphic theories, analogistic theories, scale models, analog models, substantive analogy, or analogistic models. Black (1962, Chapter 13) and Kaplan (1965, Chapter 7) clarified the various meanings and uses of the term model. According to the semantics of the word, a model instantiates some of the structure of the theoretical entities in a real substantive thing. The theory describes the structure in a symbolic representation. A model, thus, can be distinguished from the theory and hypotheses it instantiates and from the metaphor used to express the theory in terms of, or by reference to, the model. In the model, the universe of discourse of the theory is instantiated by a physical thing with visualizable parts and relations that somehow correspond with the theoretical entities and their relations. For example, the computer metaphor theme involves a theory (linguistic descriptions in information processing terms of the theoretical principles that govern the workings of cognition), the model (actual computer mechanisms and their hardware and software instantiations of the principles) and the metaphor theme itself.

The distinction between theory, metaphor, and model is a good working scheme, yet it does get fuzzy since people can conceive of a model, not only by an act of perception of a thing, but also by an intentional mental act of representation in imagery (cf. Black, 1962, pp. 220, 222). That is, some models can be mental and yet model-like. Engineering wizard Nikola Tesla could design, construct, and test machines all in the medium of mental imagery: "As a child he often confused his visions and the real world. Later his ability made it possible for him to imagine a motor, for instance, and then mentally to build the motor from scratch, run it, and then inspect it for wear" (Spurgeon, 1977, p. 65). Tesla's idea for alternating current circuitry came as a vision when he recited some lines from Faust:

The glow retreats, done is the day of toil;
It yonder hastes, new fields of life exploring;
Ah that no wing can lift me from the soil,
Upon its track to follow, follow soaring.

"As I spoke the last words, plunged in thought and marveling at the power of the poet, the idea came like a lightning flash. In an instant I saw it all." His image involved solutions to the problem of constructing a workable electric motor and a working AC system—the whole thing was designed mentally before being written down and patented (Spurgeon, p. 65).

But not all models can be imagined by all people.

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Black, 1962; Brodbeck, 1968; Gregory, 1953; Hanson, 1970; Hempl, 1965; Hesse, 1966; Hutton, 1954; Lachman, 1960; Nagel, 1961; Simon & Newell, 1956; Turbayne, 1962. They all meant pretty much the same thing by the terms they used—a model as defined here.
There are men who, when any relation or law, however complex, is put before them in a symbolic form, can grasp its full meaning as a relation among abstract quantities. Such men sometimes treat with indifference the further statement that quantities actually exist in nature which fulfill the relations. The mental image of the concrete reality seems rather to distract them than to assist their contemplations... Others, again, are not content unless they can project their whole physical energies into the scene which they conjure up (Maxwell, 1890, pp. 218–220).

Some models can be imagined and yet will retain some important functional characteristics of the stuff being modeled. Few could imagine a full working computer model, say for playing chess, yet most people could imagine a schematic flow diagram of a chess-playing program. My preference, since not all of us have the right-brained intellectual capacity of Tesla, is to regard the mental representation (conceptual, mental speech, or mental imagery) as metaphorical. The explicit sentence metaphor is called the metaphor, the actual thing is referred to as the model, and the theory and hypotheses that the model and image and metaphor instantiate are called the theory. With Hutten (1954) I think these distinctions are prudent. Certainly they are preferable to the compound ambiguities:

1. Equating models and theories or models and metaphors (Brodbeck, 1968), which has the effect of allowing one to say that theories can model other theories and laws can model other laws.

2. Defining models as being symbolic (mathematical or linguistic), which means that no thing could be a model (Duhem, 1906, Part 1, Chapter 4; Turner, 1967).

3. Calling any formal representation, mathematization, quantified hypothesis, or conceptualization a model (Bjork, 1973; Bunge, 1967; Hesse, 1953).

The distinction between model, metaphor, and theory is best seen in physics, where the theories themselves are distinct by virtue of being mathematical, the models are quite tangible, and the metaphors quite explicit. In James Clerk Maxwell’s words, the key to the metaphor and model is “a collection of imaginary properties which may be explored for establishing certain theories in pure mathematics in a way more intelligible to many minds and more applicable to physical problems than that in which algebraic symbols alone are used” (Maxwell, 1890, p. 160).

Some recent psychologists who consider the cognitive-semantic status of scientific metaphors have tried to relate them to “mental schemas” (Brown, Collins, & Harris, 1979; Collins & Gentner, 1978; Gentner, 1978; Rumelhart, 1979). Though a valid enough psychological notion, this must not be taken to
suggest that models can be of abstract content. Such is usually not the case for scientific models and metaphors. Indeed, Campbell (1920, 1953), Hesse (1966), Hanson (1970), and J. C. Maxwell (1890, pp. 155–156) claim that by definition theories in physics rely for their interpretation and intelligibility on concrete imageable referents and representations, models possibly referred to in the form of a metaphor.

The distinction between model, image, theory, and metaphor indicates another way in which some accusations that metaphors ‘hide truth’ may themselves be misguided. To illustrate this I’ll explain a widely cited scientific metaphor, the orbit metaphor for atomic structure. First, consider why this metaphor is used so much as an example—because the idea was very insightful and because the metaphor led to a concrete expression of a conceptual paradox, the wave-particle duality.

In the years 1913–1925 the quantum hypothesis was hot news. Physicist Niels Bohr began his search for a structural explanation of the behavior of atoms with Ernest Rutherford’s metaphor—Bohr called it the Atommodell. The electron, a lesser mass, could be likened to a planet orbiting a sun, the larger mass. Using the Rutherford metaphor to set the stage for a mechanistic description of atoms, Bohr was free to borrow equations from astronomy. He did. He took Hamilton’s astronomical principle of orbital angles and made it work for atoms:

If we apply the usual laws of mechanics, then we obtain directly [an equation] from Hamilton’s Principle that holds for all systems in which the frequency of the wave is a constant. . . . Let us consider an electron that revolves around a positively charged nucleus with an infinite mass. In the stationary condition of the system, the movement of the electron, without any other field, will be an ellipse with the nucleus in the focus.8

This seems to be straight-forward Keplerian astronomy. Bohr derived a specific principle, itself actually a terse mathematical expression. The motion of the electron about the nucleus (a difference between two energies) is restricted to integral multiples of Planck’s constant. This constant relates packets or quanta of energy to wavelength. This was Bohr’s insight. An electron orbit path exactly “fits” a wave, each atom has its own spectral fingerprint. One can imagine a sine-wave, as Louis deBroglie did, in undulation on a path such that an orbit of

8The German reads: “Gebrauchen wir die gewöhnlichen Gesetze der Mechanik, so erhalten wir unmittelbar aus den Hamiltonischen Prinzip. . . . [an equation] . . . dass für jedes System, in dem die Frequenz der Schwingung konstant ist . . .” (Bohr, 1914, p. 125), and, “Betrachten wir ein Elektron, das um einen positiven Kern von unendlich grosser Masse kreist. In den stationären Zuständen des Systems wird die Bewegung des Elektrons ohne irgend ein Feld eine Ellipse mit dem Kern im Fokus sein” (Bohr, 1914, p. 519). These passages are from Bohr’s important early papers on atomic structure, reprinted in Bohr, 1921.
the wave exactly evens out to a multiple of the frequency: Higher frequency, more energy, ‘‘wider orbital path.’’7

The solar system orbit metaphor for atoms does without the algebraic assistance of Planck’s constant. The Bohr principle cannot do without the math, it is math. It is in this sense that it is said a metaphor or model is crude, that it hides truth (Chapanis, 1961). But is it right to say that either the solar system model or metaphor for atom structure hides truth? No. It is the job of the theory to express all the detailed math. Why fault the metaphor for hiding what it was not intended to express, for lacking details it never hid? Witness Bohr’s own words: ‘‘When it comes to atoms, language can be used only as in poetry. The poet, too, is not so concerned with describing facts as with creating images’’ (quoted by Bronowski, 1973, p. 340).

The Role of Metaphor in Scientific Discovery

Metaphor helps in the scientific enterprise in educational or pedagogic ways—to explain a principle or theory. Metaphor can be used to learn a theory, to teach a theory, to remember a theory. It can be used to describe methods, too. My favorite is the gene experiment where enzymes are used to break up a DNA strand so that the pieces can be examined. This has been called a ‘‘shotgun blast design.’’ Metaphor, in sum, can provide a satisfying explanation of a method, theory, or phenomenon: ‘‘So that’s what you mean!’’

Philosophers regard the pedagogical aspects to be important for the cognitive status of theories, and therefore important for science itself. If a metaphor or model explains the unfamiliar in terms of the familiar, then it can do so for the theorist as well as the student (Hanson, 1970; Nagel, 1961; Pylyshyn, 1979). Indeed, it can be argued that the metaphors that really led to scientific advancement are those that evoke a deep sense of insight in scientists and students—‘‘Aha!’’—metaphors like Kekule’s snake image for the benzene ring. Kekule’s conception of atoms wriggling and turning like a snake biting its tail suggested to him that molecules may be so shaped, rather than being only chains of atoms. This metaphor solved many problems in chemistry.8

7The trick for Bohr was to show why the electron did not decay continuously toward the nucleus, emitting continuous radiation as it fell. Bohr argued for stable, limited orbits or energy states. Electrons ‘‘jumped’’ from one ‘‘shell’’ to another. From the modern perspective, this seems to have led Bohr away from a strictly Keplerian (‘‘classical’’) mechanics—the orbit atom of the 1910’s became an ‘‘onion atom’’ in the 1920’s. But the orbit atom was not ad hoc. It explained a lot, in detail, and it predicted x-ray spectra, the possibility and characteristics of synthetic elements, and it explained the properties of elements as given in the periodic table. It did leave unexplained how, in Ernest Rutherford’s terms, ‘‘an electron knows beforehand where to stop.’’ Louis deBroglie’s notion of standing matter-waves got at this.

8Feynman (1965) is an excellent source of examples of explanation that rely on playful, creative, pedagogic metaphors.
It is possible for a metaphor to be intended as purely illustrative. For example, Reichenbach (1951, p. 182) moralized Heisenberg’s uncertainty principle (also actually a terse mathematical expression): “In our intercourse with electrons we cannot don civilian clothes; when we watch them we always disrupt traffic.” But having a pedagogical intention does not preclude scientific utility (cf. Black, 1962, p. 237). In other words, metaphors do not play the role of pedagogic but otherwise sterile crutches (Chapanis, 1961, p. 120). They can be sources of creativity, and they can be deliberately used in learning situations (Collins & Gentner, 1978; Gentner, 1978).

Within science, metaphor plays many creative roles. Simply by virtue of the fact that scientists can recognize them, metaphor can add both structure and a healthy playful spirit to the inquiry. In the language of experimental design, metaphor can suggest new predictions, new demonstrations, and new experiments both of the hypothesis test and converging operation sort. A metaphor can suggest new theoretical entities or concepts, or reinterpretations of old ones. A metaphor can suggest new structural interrelations or similarities between the theoretical entities, that is, new categories of entities or properties. Not all of the concepts in a theory are translatable into observables, only some are. The metaphor may suggest new functional relations, possibly of a specified mathematical form. The relations will suggest correspondences between concepts, principles, or dispositions in the theory and certain observations. For example, Bohr’s quantization of electrons meant that an electron “jump” should show up as spectral lines of radiated energy.

In comparison to a rival theory or hypothesis, a metaphor may show how a literal description may be wrong; the metaphor may be better. A good example of a metaphor outdoing a literal theory is given by Hesse (1962). Paul Dirac elegantly interpreted the equations of quantum mechanics (a bunch of vectors) in terms of a metaphor of holes (vector spaces) and jumps in state. This led him to postulate the existence of positrons, but the literal equations would not so directly have identified the negative energy states involved for these particles. Another good example of a metaphor winning out is Mendeleev’s adherence to the concept of a periodic table—a name derived from a metaphor likening the properties of the elements to acoustic (periodic) harmonics. Mendeleev used cards identifying the elements, and he tacked the cards up so that they fell into “suits” according to their properties. The concept of a periodic table ran into snags since it assigned some elements the “wrong” properties (i.e., atomic weights). The discovery of isotopes cleared the classification problem up, and Mendeleev’s concept was vindicated.

**MAKING A METAPHOR**

Hanson (1958) and Simon (1973), and others, proposed that the “logic” of scientific discovery is a psychological affair, a matter of heuristics and effi-
ciency, and not a philosophical affair of deductions, inductions, and prediction. Some in the philosophy of science who realized this, like Popper (1959, pp. 31–32), argued that the topic of scientific discovery was therefore irrelevant to the philosophical-logical analysis of theories. The psychologist who follows Simon's lead need not necessarily view scientific discovery and theorizing as irreducibly intuitive, irrational, or even mystical. The creative process in scientific problem-solving can be described (metaphor seems to be one important way of describing it), and the description may indeed have implications for the philosophy of science. For instance, as James Deese (1972, Chapter 2) pointed out, different theories in different disciplines will have different domains to explain, and since human theorists may understand the domains in different ways, the theories may differ in form, as well as content, and they may have to be assessed by different kinds of metatheoretic criteria. A theory of personality may be written as words and will have to make intuitive sense to psychologists. A theory in physics may make intuitive sense to physicists, but will have to be written at least in part with mathematics. A metaphor may be necessary for one domain of theory and yet metaphor may not be needed for another domain.

Suppose there is a phenomenon or concept or theoretical entity for which the scientist seeks an understanding. The Concept, as I'll label it, is to appear as the Topic in a metaphor. The Concept may begin with some properties or affordances that are literally and explicitly dictated by the principles, measures, and entities already in the theory. The Concept may also start off with some properties from the ordinary language if the Concept happens to involve a term in the ordinary language (e.g., atom, ego, mind). The Concept will be used in a metaphor with some Vehicle. The Vehicle will also begin with some literal properties due possibly to the use of the Vehicle term in ordinary language (e.g., solar system, helmsman, computer) or possibly due to the reference the Vehicle term makes to some substantive theory from a domain other than that of the Topic (e.g., Keplerian mechanics, information processing terminology). As a consequence of the metaphor, the properties of the Vehicle may be regarded as being distinguishable into at least two subsets. Certain properties of the Vehicle can be regarded as literally applicable to the Topic, some as figuratively applicable to the Topic. If the Vehicle refers to a domain with its own substantive theory, laws that describe the Vehicle may be applied to the Topic Concept.

Property Correspondence and Property Similarity

For a metaphor to work some of its implications must fit with the rest of the theory of which the Topic Concept is a part. That is, some of the properties

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*Here, I dance around the psycholinguistic issue of "features." Feature systems in semantics are really a special kind of metaphor for representing the distinctions we draw. As such, there's nothing necessarily wrong with them. Serious philosophical and psychological problems arise when features are granted ontological status, that is, when it is assumed that features represent something that is really "out there," or really "in there," as the case may be.
suggested by the Vehicle must correspond with properties of the Topic as dictated by the theory. If none of the properties correspond, the metaphor might never have been conceived. To illustrate, suppose we “turn a metaphor on its head” and try to explain solar systems by saying that they are like atoms. With a little “ad hocery” the Bohr equations can be used to make predictions of the orbits of the planets. This is a great exercise in number-crunching, but little more, for the metaphor, Solar systems are atoms, fails because it refers to an inadequate model. The set of literal properties of atoms does not seem to contain properties that clearly correspond with those of solar systems as dictated by the astrophysical equations of gravity and acceleration.10

Some overlap of the Topic and the Vehicle is inevitable because anything can be seen as similar to anything. But overlap is not enough for a metaphor to have value. It may reflect only the hunch-seeking stage where metaphorizing and theorizing can be more like a remote associates test. Jones’ theory says that cancer cells act like springs in response to traumas. Both certain cancers and certain springs follow exponential laws. So what?

The utility of a metaphor shows up when it suggests (“new”) properties in the Vehicle that were not attributed to the Topic on the basis of the theory and that could not be attributed to the Topic on the basis of the theory alone. Some of the literal properties of the Vehicle may not be applicable to the Topic and may even trivialize the theory. An atom (Topic) cannot be said to have a diameter of billions of miles (literally true of the solar system), but it can be said to have a limit to its diameter, and the Bohr equations could be used to set bounds on an atom’s “diameter.” In other words, a property of the Vehicle may seem irrelevant or trivial or absurd when applied to the Topic Concept in the theory—the property will not correspond with a property that is given by the theory (Hesse [1966] called this the “negative” part of the analogy!). However, a derivative or related property might be relevant! A once-literal property of the Vehicle is conceived and the experimenter realizes that something like that property may be applicable to the Topic. The experimenter can try and find ways of coordinating the “new” property of the Vehicle with some heretofore undescribed property of the Topic as yet not directly attributed to the Topic by the theory. Thus, the metaphor entails modification of the theory by redefining the Topic. But the redefinition occurs in a certain way . . . the use of metaphor in science can be, must be, described as complex mapping operations, not a single mapping based on property correspondence, that is, overlap of Topic and Vehicle domains. The similarity of Topic and Vehicle depends not only on the perception of property correspondence but also on the perception (creative discovery) of property similarity.

10For scientific metaphors, the Topic is based not only on the meanings of the term from ordinary language, but also on the theory. The Vehicle may also tap into a theory (e.g., Bohr’s metaphor, Atoms are solar systems, tapped into principles from Keplerian astronomy). Thus, scientific metaphors may not be symmetrical (see Connor & Kogan, this volume). There may be little reason to suppose why scientific metaphors might or should be symmetrical.
The Metaphoring Process

Metaphoring cannot be regarded as a static aspect of theorizing. One cannot be certain a priori about all the properties in the Vehicle that will make for a useful metaphor as long as one cannot know how or where to separate the Vehicle into literal and figurative properties, in other words, as long as the Topic is open for further conceptualization. Thus, perhaps one cannot know how to decide correctly about a theory only on the basis of metaphoricalness. For example, aether theory involved a hypothetical medium for the transmission of energy, a metaphor. But aether theorists could not have known it was a blind alley until its implications were pursued. One cannot be certain that all the relevant properties of the Vehicle have been found. To presume so would be to adopt a static view of the science process. Kaplan (1965) said it less formally: "There is no limit to the metaphors by which we can effectively convey what we know. . . . It would be rash indeed to attempt a priori to set limits on the fruitfulness of models" (pp. 287, 292). To perpetuate a sharp literal-figurative distinction is, in effect, to rule out the utility of metaphors. Metaphors must be pursued or intuited away: There can be no rational basis for a decision until the metaphor has been explored. To have a metaphor means to have hope.

Psychological Hypotheses About Metaphor Comprehension

How does this analysis compare with available views about how metaphors are understood? Numerous scholars have speculated about metaphor comprehension. To make sense of the various positions I consider here some general viewpoints and only a few specific theorists. In the general tradition of rhetoric and the notion of "poetic compression" are those who claim that it may be impossible to give a complete literal paraphrase of some metaphors, or that it may be impossible to fully specify the rules for comprehending metaphors (Black, 1962; Campbell, 1975; Ortony, 1975; Henle, 1958). The distinction between theory, model, and metaphor suggests that as far as the theory is concerned, the model is an interpretation. It is not the interpretation. But whether or not a metaphor can be given a (verbal) literal paraphrase need not keep us from analyzing and using our scientific metaphors. The moral is that the meaning of metaphors is open—there may always be something new to learn.

In the Aristotelian tradition are those who consider metaphor to be a statement of resemblance, simile, analogy, or comparison in which the topic and vehicle are somehow regarded as having shared features (Fraser, 1979; Nemetz, 1958). Property correspondence is an important aspect of the use of metaphor in science. But a theory is not metaphorical just because it may point out correspondences of features, nor does the content of scientific metaphors consist only of statements of shared features. The present analysis fits more with the tradition following Richards (1936). The words of a metaphor are said to "interact" and to be comprehended together to allow the creative discovery of a new meaning
(Berggren, 1962; Ortony, 1979). In the present analysis this is called the perception of property similarity.

There are more detailed theories in psychology that are processing views. In general, they assert that the literal meaning of a metaphor is always comprehended first, resulting in an anomalous reading. The literal meaning and structure are then used to “compute” or derive the intended figurative meaning. This notion, or subtle variations of it, is common to many scholars (e.g., Clark & Clark, 1977; Cohen, 1979; Kuhn, 1979; Searle, 1979; Smith, Rips, & Shoben, 1974). On some thought, this view actually suggests entire classes of possible process-representation hypotheses that can be used to make predictions about, say, the time it takes people to comprehend metaphors as opposed to literal statements. In Kintsch’s (1974) version, any sentence that contains a contradiction of semantic features (oxymoron) is a potential metaphor. Its figurative meaning is derived by special transformation and analogy rules. One could postulate that metaphorical meaning relies on the filtering out of usual word meanings and the discovery of unusual ones. If meanings are scanned in parallel, one would not necessarily expect it to take longer to comprehend metaphorical meaning. On the other hand, even with a parallel search process, if the metaphorical word meanings are stored low down in a push-down stack then it might take longer to comprehend metaphors even if there is not a special metaphor comprehension process.

Metaphoring in science is often a very long and drawn-out process. Metaphor themes have long lives because of thematic inclusiveness, but even a specific metaphor can take years to unravel. In science one can latch upon a metaphor or intuitively appealing vision (e.g., waves) and ride the vision for years, for generations, trying to unpack its implications (e.g., Bohr equations, wave-particle dualities, etc.). Psychological processing hypotheses about the creation of metaphors (the scenario of interest in the case of scientific discovery and use) are nearly nonexistent, excepting the accounts by psychodynamic and motivational theorists. But on a fundamental level, the process of metaphorizing in science does not seem to be one of an exclusively sequential series of operations based on the recognition of anomaly. Scientists do sometimes try and make sense out of anomalous phenomena. Metaphors do not begin anomalous, but meaningful—concepts are being compared. It is only after the analysis, perhaps when it all is put down in linguistic form (i.e., after the original insight) that what come to be labeled as the “unacceptable” or “anomalous” aspects of a metaphor can possibly be singled out to have their sway over the useful aspects.

BACK TO PHILOSOPHY

Finally, a return to consider the sources in philosophy in light of the present analysis. There is an important complication in the sparring match over the use of
metaphors in science, a complication yet to be brought explicitly into the ring (cf. Black, 1962, p. 236). One can be either for or against the use of metaphor in theorizing without necessarily being either for or against the use of metaphor in theories. Those philosophers of an operationist persuasion who see metaphor as a linguistic curse might want to eliminate metaphor altogether. On the other hand, those who advocate the use of metaphor often rely on examples that seem to involve metaphor in theorizing. On close inspection of some scientific metaphors, however, the metaphors do seem to be, at least in part, actually "in" the theory.

It would be possible to rewrite the Bohr atom theory (1921), eliminating all the words and leaving only the math. Some philosophers would say that what is left is the theory. That may be, but only to a person who knows how the math is to be interpreted. Is the issue whether to include in the theory the metaphorical parts of the interpretation of the math? The metaphorical parts helped Bohr generate the math—they were a part of Bohr's theorizing. But, it turns out, in Bohr's theory metaphorical expressions occur in the derivations of the math and in the sentences that exposit theory. For some equations and derivations, as well as sentences, some parts seem to properly be called astronomy and some parts seem to be atomic physics. (See Footnote 6.) For scientific metaphors, as exemplified in this chapter, the metaphor is important in theorizing and it can be a part of the theory. Psychologically, comprehension and theorizing are all we really have, anyway. There are no theories—if theories are to be conceived of as written "carriers" of meaning with an existence independent of a cognizing theorist. Written "theories," like words, are stimulus symbols that have to be the objects of someone's mental acts to be labeled as "theories." When a metaphor is used as part of a written exposition of a theory, it reflects the fact that the Vehicle was used in theorizing to define or redefine (at least) the Concept (Topic) in the theory. The metaphor Vehicle interacts with the theory. So some of the metaphor, at least, is a "part" of the theory. To J. C. Maxwell, a scientific metaphor is a "golden mean"—it stands halfway between the physical analogy or model and the theory and mathematization. It is generative of both, and a part of both.

Assuming that a metaphor or part of a metaphor can be included in a theory, operationists might want to chop up the metaphor, to eliminate the figurative Vehicle from the theory while including the redefined Topic Concept. That is, they would try by some logical means to make the sets of literal and figurative properties separate. All the meaning of the Topic Concept would be regarded as coming from the properties given by the theory plus whatever notions came into the theory from the metaphor before the metaphor was thrown out. This disjunction, interestingly, would occur as a logical consequence of writing the "Ramsey sentence" of the theory (see Braithwaite, 1953, p. 58). Simply, each occurrence of the concept that is used metaphorically would be replaced by an abstract symbol that would denote a list of the properties of the concept dictated by the
theory. In the grandest spirit of operationalism-positivism, this would indeed 'demetaphor' the theory and eliminate surplus meaning, but it also eliminates any further utility the metaphor might have had.

The present analysis supports a claim made by Popper, by Carnap, and by G. Maxwell (1970) that there can be no strict inductive justification (a priori) for belief in scientific (here, metaphoric) principles. Hesse argued somewhat similarly that the postulation of new entities for a pre-existing theory must involve metaphorical extensions since a strictly deductive or rational method cannot make such postulations without recourse to further thought and experiment. One may not be able to see which characteristics of a model can be exploited and which are irrelevant. Hutten (1954) and Lachman (1960) argued that models may be evaluated a priori, that is, by rational rather than by empirical means, according to their scope and precision. Yet, they too maintained that there can be no sufficient rational grounds for determining how well a model will work out. As Berggren (1963) put it, "By the interaction of formal theory with experimentally determined fact both are transformed yet preserved... neither scientific nor poetic metaphors can reveal except by creating, precisely because they partially create what in fact they reveal" (p. 462). In terms of the present analysis, there is no deductive means for deciding exactly which metaphor to introduce (or throw out), or for deciding which correspondence rules to use to fit the redefined terms back into the theory. The moral? Don't reject any metaphor offhand because of metaphoricalness.

Although an exploration of the meaning and implications of metaphor is necessary to determine whether the metaphor will pay off, science does not act this way. Metaphors get rejected for some fundamental reasons involving the theorist's motivations, the Zeiggeist, etc.

I believe that this exercise has been fruitful, partially for the listing out of the uses and misuses of metaphor in science. It was not clear before, nor is it crystal clear afterwards, how different types of scientific metaphors fit in with scientific progress. The situation is complex; many specific questions can be asked. In what cases, if any, will a metaphor serve a necessary scientific function? How must the nature of a metaphor fit in with how people understand the domain of a theory? I have described the mixed scientific metaphor, the scientific metaphor theme, and the scientific metaphor that redefines a concept from a theory. How can these, and possibly other forms of scientific metaphors, be reliably distinguished? Would a knowledge of the rhetorical forms of metaphors assist people in problem-solving situations? How can cognitive psychologists describe more aspects of metaphoring, such as the unconscious emotive mental work that results in insight and the creation of new meanings? It is now pretty much old hat in philosophy of science to recognize the role of psychological factors in the scientific enterprise. Beyond this, this chapter suggests that more specific approachment between the disciplines would be useful—to examine the more specific types of cognition and to turn ideas such as those presented here into
principles that working scientists and educators might make use of. I hope, at least, to have encouraged debate on all this.

Perhaps a rhetorician would have claimed at the outset that the comprehension of meaning must come before the discovery of merit. Both poetry and science can be means of validating what we apprehend. But it seems to be a long way from actual poems to actual theories and there are few explicit bridges between them.

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