## Chapter 6

# Models, Metaphors and Analogies

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Metaphor and analogy, often not distinguished very sharply, are manifestations of ways in which information can be expressed and, as some would argue, is processed in our mind. This is so not only in everyday situations, but also in the sciences where information is presented in highly systematic and methodologically specialized ways. Appreciating that metaphor and analogy are pervasive in everyday situations and in the language we use to describe them, it comes as no surprise to encounter them in science also. In tune with this assumption, the analysis of metaphor and analogy has had considerable influence on the analysis of scientific models. Taking models as manifestations of how scientists develop interpretations of empirical information in their subject area, the metaphor approach to scientific models can elucidate how scientists create and formulate interpretations of aspects of the empirical world.

I shall begin by outlining what scientific models are, and then provide a review of the treatment of analogy in the philosophy of science because the use of analogies is central for scientific modeling as well as for metaphorical language use (pp. 108–13). Issues guiding the analysis of metaphor and the application of this analysis in science are then presented (p. 114), while the next section (p. 118) deals with the specific claim that scientific models are metaphors. The final section (p. 121) highlights current issues that have emerged from the discussion of scientific models as metaphors and still need to be resolved. It also summarizes the relationships between model, metaphor and analogy as examined here.

### Models

I consider the following as the core idea of what a scientific model is: A model is an interpretative description of a phenomenon that facilitates access to that phenomenon. (I take "phenomenon" to cover objects as well as processes.) This access





can be perceptual as well as intellectual. Interpretations may rely, for instance, on idealisations or simplifications or on analogies to interpretative descriptions of other phenomena. Facilitating access usually involves focusing on specific aspects of a phenomenon, sometimes deliberately disregarding others. As a result, models tend to be partial descriptions only. Models can range from being objects, such as a toy aeroplane, to being theoretical, abstract entities, such as the Standard Model of the structure of matter and its fundamental particles. As regards the former, scale models facilitate looking at (perceiving) something by enlarging it (e.g. a plastic model of a snow flake) or shrinking it (e.g. a globe as a model of the earth). This can involve making explicit features which are not directly observable (e.g. the structure of DNA or chemical elements contained in a star). The majority of scientific models are, however, a far cry from consisting of anything material like the rods and balls of molecular models used for teaching; they are highly theoretical. They often rely on abstract ideas and concepts, frequently employing a mathematical formalism (as in the big bang model, for example), but always with the intention to provide access to aspects of a phenomenon that are considered to be essential. Bohr's model of the atom informs us about the configurations of the electrons and the nucleus in an atom, and the forces acting between them; or modeling the heart as a pump gives us a clue about how the heart functions. The means by which scientific models are expressed range from the concrete to the abstract: sketches, diagrams, ordinary text, graphs, mathematical equations, to name just some. All these forms of expression serve the purpose of providing intellectual access to the relevant ideas that the model describes. Providing access means giving information and interpreting it, and expressing it efficiently to those who share in the specific intellectual pursuits. Scientific models are singularly about empirical phenomena (objects and processes), whether these are how metals bend and break or how man has evolved.

One might object that, according to my explication, more or less anything that is used in science to describe empirical phenomena is a model, and indeed this seems to be the case. The tools employed to grant us and others intellectual access are of great diversity, yet this, in itself, is no reason to deny them the status of being constituents of models. Modeling in science is pervasive, and it has become increasingly varied and more and more abstract. The sheer diversity of models makes it unlikely that *all* models are metaphors or rely on analogies, but some do, and these are the focus of this article.

When scientific models are associated with metaphor and analogy, the topic is how scientists develop and convey scientific accounts for empirical phenomena encountered in their research. The idea of viewing scientific models as metaphors appeared in the 1950s (Hesse, 1953; Hutten, 1954) and was taken up in Mary Hesse's (1966) work in the 1960s with the aim to show that metaphorical models and analogy are more than heuristic devices that can be jettisoned once a 'proper' theory is in place. (For a review of the work at that time and before, see Leatherdale (1974).) Work on models and metaphor continues to be discussed to this day (Paton, 1992; Bhushan and Rosenfeld, 1995; Miller, 1996; Bradie, 1998, 1999;

Bailer-Jones, 2000b), and it usually concurs with the rejection of the received opinion that theories prevail over models – a rejection which need not be linked to a metaphor view of models, however (Cartwright, 1999; Giere, 1999; Morgan and Morrison, 1999). Metaphor, in this context, is seen as very closely tied to analogy, just as models are closely tied to analogy (Achinstein, 1968; Harré, 1988). In addition, model, metaphor and analogy have been popular notions in their own right over the past decades. There is a great deal of work on analogy coming from artificial intelligence research (Falkenhainer et al., 1989; Holyoak and Thagard, 1989; Hofstadter, 1995) and from cognitive psychology (Gentner and Markman, 1997; Van Lehn, 1998). Metaphor has been addressed in philosophy of language (Davidson, [1978] 1984; Searle, 1979) as well as in cognitive linguistics (Kittay, 1987; Langacker, 1987; Lakoff and Johnson, 1980, 1999; Lakoff, 1993). Today, the study of scientific models as metaphors or analogies in philosophy cannot be separated from the study of these phenomena in neighboring subjects, nor should they. On the other hand, drawing from a large number of fields with different aims and research questions does not make progress in research on scientific models any swifter. To draw inferences about the use of metaphor and analogy in scientific modeling, one needs to tread carefully when assessing whether findings from neighboring disciplines can be integrated – while integrating them is likely to be an important stepping stone in the analysis of scientific models. In any case, the idea that analogy centrally occurs in human information processing and knowledge generation is common to work done in all these areas.

## Analogy

The Greek word analogy (αναλογια) means 'proportion', e.g. 2 is to 4 as 4 is to 8. To use analogy for illustration is a common occurrence in Greek thought, as when the pre-Socratic Thales of Miletus claims that the earth floats on water like a piece of wood would (Aristotle, *De Caelo*, B 13, 294a28 f.) Analogy is often understood as pointing to a resemblance between relations in two different domains, i.e. $A$ is related to $B$ like $C$ is related to $D$. To give an example, the electrons in an atom are related to the atomic nucleus like the planets are related to the sun. The term "formal" analogy points to relations between certain individuals of two different domains that are identical, or at least comparable. Such an identity of structure does not require a "material" analogy, that is, the individuals of the domains are not required to share attributes (Hesse, 1967). Both the motion of electrons and planets is determined by an attractive force which is why they orbit around the atomic nucleus and the sun respectively, even though the causes of attraction are not the same (gravitational versus electrostatic) which is why the relationships are perhaps more correctly called "comparable" than "identical." Although electrons and planets share the relationship of attraction, they differ hugely in attributes, such as size and physical make-up.





Analogies can exist as formal relationships between phenomena or, rather, between the theoretical treatment of phenomena. Pointing to examples, such as light and sound waves or magnetism and dielectric polarisation, Pierre Duhem stresses that "it may happen that the equations in which one of the theories is formulated is algebraically identical to the equations expressing the other. . . . [A]lgebra establishes an exact correspondence between [the theories]" (Duhem, [1914] 1954, p. 96). To find such a correspondence serves "intellectual economy," and it can also "[constitute] a method of discovery" by "bringing together two abstract systems; either one of them already known serves to help us guess the form of the other not yet known, or both being formulated, they clarify each other" (Duhem, 1954, p. 97). There is "nothing here that can astonish the most rigorous logician"; it is a strategy in perfect agreement with "the logically conducted understanding of abstract notions and general judgements" (1954, p. 97), and yet, Duhem judges analogies in science as heuristic, thus as no longer essential once a theory is formulated.

Norman Campbell ([1920] 1957) treats analogy in science as somewhat more crucial for his notion of theory. In his account a theory contains a hypothesis, a set of propositions of which it is not known whether they are true or false about a certain subject (for my purposes, "first subject"). If the ideas expressed in these propositions were not connected to some *other* ideas (associated with a "second subject"), they would be, according to Campbell, no better than arbitrary assumptions. As the propositions constituting the hypothesis are not themselves testable, they require some kind of confirmation via a translation into *other* ideas, i.e. ideas about a second subject, whereby the latter are known to be true through observational laws. Campbell's example is the kinetic theory of gases (first subject) being the hypothesis formulated in terms of a set of propositions. The second subject would then be "the motion of a large number of infinitely small and highly elastic bodies contained in a cubical box" (Campbell, 1957, p. 128). For the latter, laws are available so that it can be known which propositions concerning the second subject are true. The first subject, Campbell proposes, benefits from this knowledge: Via a "dictionary," the transition from first to second subject can be made, and the knowledge about the small elastic bodies illuminates the case of interest, i.e the first subject, and is employed to test the hypothesis indirectly. Campbell asserts: "[i]n order that a theory may be valuable . . . it must display an analogy. The propositions of the hypothesis must be analogous to some known laws" (Campbell, 1957, p. 129). In modern terms, the small elastic bodies in the box would be considered as a model, though Campbell does not use this term. While Campbell greatly advertises the importance of analogy, he seems little concerned with its advantages for the practice of science, that is for discovery or teaching.[1]

Besides analogies *between* the theoretical treatments of phenomena which Campbell considers, Hesse (1966) also proposed that scientific models are to be viewed as analogues[2] to the aspects of the real world that are their subject (Hesse, 1953, p. 201); see also Hesse (1967) and Harré (1970, p. 35). Rom Harré calls this "[a] behavioural analogy between the behaviour of the analogue of the real productive process and the behaviour of the real productive process itself" (1988, p. 127). In contrast to this, most subsequent discussions about the formal relationship of analogy concern analogies between theoretical treatments of different empirical phenomena and the examination of the potential of the use of analogy for purposes of "intellectual economy" and for "scientific discovery." For this, the study of nineteenth century science, specifically the work of Kelvin, Faraday, and Maxwell, provides numerous case studies (Duhem, [1914] 1954; Campbell, [1920] 1957; Hesse, 1953). Examples include the analogy between heat and electrostatics, where the same equations can be employed in both areas, with temperature corresponding to electrical potential and source of heat to positive charge (North, 1980, p. 123), or Maxwell's approach to electromagnetism by analyzing an electromagnetic ether in terms of vortices along lines of magnetic force (Harman, 1982, 1998). From such examples, analogy can be recognized as a constituent of scientific argument (North, 1980) and can be appreciated as cognitively relevant. It seems plausible that the development of models of new phenomena benefits, in many cases, from considering analogies to other, already existing and more familiar models, even if these appear to belong to quite different phenomena. The key point is precisely that the two phenomena are not the same. Proclaiming one thing to be analogous to another is not simply a statement about what the two subjects have in common. Rather, in the interesting cases of analogy, there are differences between the relations and attributes present in both domains; these are called "disanalogies" or "negative analogies." Electrons and planets are attracted by the atomic nucleus and the sun respectively, but not through the same kind of force. Any positive analogy comes with negative, and also sometimes with neutral, not yet explored analogies (Hesse, 1966, 1967; Harré, 1970, 1988). The effective use of analogy presupposes that its users know, or can explore, what the positive and the negative analogies between two domains are.

Analogy is often thought to occur in science because it supports a central function of models: explanation (Harré, 1960; Nagel, [1960] 1979, p. 107; Hesse, 1966; Achinstein, 1968). According to some authors, models being explanatory mostly coincides with them being developed on the basis of an analogy to some other object or system (Achinstein, 1968, p. 216). Explanation is thus linked to making the transition from something unfamilar to something more familiar: "The analogies help to assimilate the new to the old, and prevent novel explanatory premises from being radically unfamiliar" (Nagel, [1960] 1979, p. 46). Analogy counts as a plausible candidate for providing explanations because the use of more familiar and already accepted models (models that have led to understanding in different, but comparable situations) appears as a promising strategy in a new context. Correspondingly, Peter Achinstein states:

> Analogies are employed in science to promote understanding of concepts. They do so by indicating similarities between these concepts and others that may be familiar or more readily grasped. They may also suggest how principles can be formulated





> and a theory extended: if we have noted similarities between two phenomena (for example, between electrostatic and gravitational phenomena), and if principles governing the one are known, then, depending on the extent of the similarity, it may be reasonable to propose that principles similar in certain ways govern the other as well (Achinstein, 1968, pp. 208–9).

Achinstein quotes as examples, among others, the analogies between the atom and the solar system, between waves of light, sound and water, between nuclear fission and the division of a liquid drop, between the atomic nucleus and extranuclear electron shells, and between electrostatic attraction and the conduction of heat (Achinstein, 1968, pp. 203–5).

Exploring how people understand is the subject of cognitive psychology, where research into analogy has generated considerable interest over the last twenty years; for overviews, see Gentner and Markman (1997) and Holyoak and Thagard (1997). Results involve that analogy can be analyzed in terms of similarity, similarities of relationships (e.g. encountering interference in water waves *and* in light) and similarities of object attributes (e.g. oxygen and helium being gaseous at room temperature). Correspondingly, analogy can consist of attribute mappings as well as of relationship mappings, but Gentner (1983) produces empirical evidence according to which mappings of relations tend to be favored and considered the "deeper" analogies by those who are confronted with the analogies. Analogies become relevant, in science in particular, when they highlight a "system of connected knowledge, not a mere assortment of facts" (Gentner, 1983, p. 162). Furthermore, there is a preference for comparing items that are similar because their differences are "alignable." Items that are dissimilar have little in common, their differences are not alignable, and they thus have a smaller impact on people's perception of similarity. Gentner and Markman view "the ability to carry out fluent, apparently effortless, structural alignment and mapping [as] a hallmark of human cognitive processing" (1997, p. 53).

Acknowledging the importance of analogy in scientific reasoning (Hesse, 1966; Gentner, 1982; Harré, 1988) makes it tempting to identify scientific modeling with drawing analogies. However, while many models have their roots in an analogy, such as Thomson's plum pudding model of the atom or Bohr's model of the atom based on the solar system, few existing models in science have not developed beyond the boundaries of the analogy from which they originated, and others may simply not have their origin in an analogy at all (Bailer-Jones, 2000b). Moreover, an analogy is a relationship between things or processes while a model is a type of description about some thing or process. If anything, a model could be an analogue, but this is not the issue because the way to evaluate a model is not to judge whether it is analogous to something, but whether it, as it stands (analogous or not), *provides access* to a phenomenon in that it interprets the available empirical data about the phenomenon. An analogy used for modeling can act as a catalyst to aid modeling, even though the aim of modeling has nothing intrinsically to do with analogy. It is, of course, more than reasonable to stress the importance of analogy in the modeling process given that analogy is one of the cognitive strategies available for creative discovery from which scientific models result.

## Metaphor

A metaphor is a linguistic expression in which at least one part of the expression is transferred (μεταφερειν) from one domain of application (source domain), where it is common, to another (target domain) in which it is unusual, or was probably unusual at an earlier time when it might have been new. This transfer serves the purpose of creating a specifically suitable description of aspects of the target domain, where there was no description before (e.g. "black hole") or none was judged suitable. Martin and Harré (1982, p. 96) call these "crises of vocabulary." Metaphoric expressions are used for descriptions, and the occasion for the use of metaphor arises when the two domains between which the transfer occurs can be viewed as being related: by similarity of object attributes, or by similarity of relationships (Gentner, 1983). Thus the relationship of analogy is usually an important factor in being able to understand a metaphor. However, establishing the importance of analogy for understanding a metaphor is not to claim that the analogy necessarily precedes the metaphor. One could equally argue that it is the metaphor that prompts the recognition of an analogy – it is feasible that *both* types of cases occur; the latter possibility would still warrant that the metaphor is connected to the analogy (or analogies) suggested by it: "every metaphor may be said to mediate an analogy or structure correspondence" Black ([1977] 1993, p. 30). In astronomical observations, one talks about signal-to-noise ratio. *Signal* is the light emitted from the object one wants to observe; *noise* represents the uncertainty in the signal (and the *background*) due to quantum fluctuations of photon emission and thus represent a limit to the precision with which the signal can be determined. The analogy connected with the noise metaphor is to a sound signal, e.g. emitted from an interlocutor whilst noise from other people talking and perhaps a nearby road needs to be separated from the signal so as to make out the information of interest. As listeners dealing with sound waves, we are quite proficient in filtering out all those unpredictable random frequencies that could prevent us from making out the signal in which we are interested, and a comparable skill would be required for optical waves in astronomy. Without this analogy, the metaphor of noise, as used in astronomy, is incomprehensible.

The claim that scientific models are metaphors is tied to the fact that often an analogy is exploited to construct a model about a phenomenon. Thus, if scientific models are metaphors, then analogy is an important factor in this. "The brain is the hardware for which a child gradually develops suitable software" implies an analogy between data processing in a computer and the cognitive development of a child, just like the liquid drop model of the atomic nucleus suggests an analogy





between the atomic nucleus and a liquid drop in that the overall binding energy of the nucleus is, in approximation, proportional to the mass of the nucleus – like in a liquid drop. The view that scientific models are metaphors depends, of course, on what metaphor is taken to be, other than metaphors being connected to analogies. Only in view of that can one assess how the analysis of metaphor translates into an understanding of scientific models. I start by focusing on the first of these issues.

The analysis of metaphor is traditionally conducted by contrasting literal with figurative (or metaphorical) language (a distinction on which I shall shed some doubt below). This requires the reliance on an intuitive or common-sense understanding of "literal," despite the difficulty of pinpointing what makes literal language literal. Of course, we have a sense in which talk about "little green men" appears metaphorical in comparison to "extraterrestrial intelligent life." "Literal" implies, by default, that an expression is not transferred from another domain, i.e. is "more directly" about something and perhaps more "typical," "common," "usual" or "expected." Inevitably, such a classification remains unsatisfactory, partly because we do not tend to find metaphorical statements more difficult to comprehend than so-called literal statements that could stand in their place (Rumelhart, [1979] 1993). Metaphors, moreover, can be perfectly usual and familiar. Nobody stumbles over *processing information* or *developing software* said of the mind, or a *phylogenetic tree* merely because it is no oak, beech, lime or fir. Just as we understand the brain-as-computer metaphor, we understand that a phylogenetic tree displays dependency relations of a group of organisms derived from a common ancestral form, with the ancestor being the trunk and organisms that descend from it being the branches. Most metaphors are understood with ease which indicates that there are no grounds to treat them as deviations of language use. On the contrary, they are pervasive and central (Richards, 1936).

While there may be no clear-cut distinction between literal and metaphorical, one can still observe different "degrees" of metaphoricity, and the conditions under which we are capable of comprehending metaphors can be outlined correspondingly:

A Even though a metaphor is entirely novel to us, we are endowed with the cognitive skill to interpret it just as easily as if we were familiar with that particular use of terminology.

B While we recognize a phrase as metaphorical in principle, we are so familiar with the particular type of metaphor that the metaphor is neither unusual nor unexpected; the brain-as-a-computer metaphor is an example of this. Another is to think of the energy distribution of a system as a landscape with mountains and valleys, and a gravitational force that is responsible for differences in potential energy depending on height, exemplified in phrases such as *potential well* or *tunnelling through a potential barrier*.

C We are so familiar with what once was a metaphor that a special effort would be required to recognize it as such; examples are electric *current*, electric *field*, *excited* state or a chemical *bond forming*, *breaking*, *bending*, *twisting* or even *vibrating*. Such metaphors are "dead"; they are pervasive in our language and they appear to us just like literal expressions (Machamer, 2000), especially as sometimes they are our *only* expression for what they describe. Historical priority would probably be the only grounds on which a *current* of a river or a *field* ploughed by a farmer would be judged more literal than *electric current* or *electric field*.

These degrees of metaphoricity are only partially related to the novelty of the metaphors, because some metaphors, (unlike those in C, or even in B), will always remain recognizable as metaphorical, no matter how familiar and well-known they have become. An example would be "God does not play dice" expressing resistance to indeterminacy in physics.

In the following, I shall focus on metaphors of the first and second kind, namely metaphors that have not become and perhaps never will become entirely ordinary and are consequently not quite so easily taken for literal language. In these cases, it is often presumed that the metaphorical phrase has a special quality in the way it communicates information, sometimes referred to as "cognitive content" (Black, 1954). A "strong cognitive function" is assigned to metaphor when "a metaphorical statement can generate new knowledge and insight by *changing* relationships between the things designated (the principal and subsidiary subjects)" (Black, [1977] 1993, p. 35). This is thought to happen because metaphor inspires some kind of creative response in its users that cannot be rivalled by literal language use. Think of "little green men" as a metaphor for extraterrestrial intelligent life, as it is used in science, not restricted to fantasy. Of course, the original domain of that expression is fantasy, and there "little green men" may mean exactly that: small green people. If the phrase is used in science contexts, however, the implicit reference to fantasy highlights the fact that we have no idea of what extraterrestrial intelligent life might be like. Something naively and randomly specific – little green men – is chosen to indicate that there is no scientific way of being specific about the nature of extraterrestrial intelligent life. Precisely that we do not know what extraterrestrials are like is what we can grasp from the phrase "little green men." No amount of interpreting the literal phrase "little green men" without a system of "associated commonplaces" (Black, 1954); "implicative complex" in Black ([1977] 1993) would enable us to achieve this, thus knowledge of the domain of application is crucial. "Little green men" is transferred from the domain of fantasy to the radically different domain of science where one would not usually expect this expression. Nonetheless, there is no reason to think that the metaphor of little green men can be less reliably interpreted and understood by its recipients than any phrase from the "right" domain of language use, such as "not further specifiable forms of extraterrestrial intelligent life." On the contrary, according to Max Black's interaction view which goes back to Ivor Richards (1936), we even gain insight through the metaphor that no literal paraphrase could ever capture; a metaphor cannot be *substituted* by a literal expression. Neither is it simply a *comparison* between the two relevant domains, as in an elliptical simile ("Extraterrestrial intelligent life is (like) little green men"), because, as Black suspects, metaphor can *create similarity*.[3] If this is true, metaphorical meaning can no longer be viewed as a sheer function of the literal meaning of linguistic expressions belonging to a different domain. Instead, the proposal of the interaction view is that the meanings of the linguistic expressions associated with either domain shift. The meanings of the expressions are extended due to new ideas that are generated when the meanings associated with primary and secondary subject interact. The interaction takes place on account of the metaphor which forces the audience to consider the old and the new meaning together.





While the idea that scientific models are metaphors appears in Black (1962),[4] it was further explored in Hesse (1966, pp. 158–9) who draws from the interaction view:

> In a scientific theory the primary system is the domain of the explanandum, describable in observation language; the secondary is the system, described either in observation language or the language of a familiar theory, from which the model is taken: for example, "Sound (primary system) is propagated by wave motion (taken from a secondary system)", "Gases are collections of randomly moving particles."

Hesse postulates a meaning shift for metaphors. Their shift she takes to be in pragmatic meaning that includes reference, use and a relevant set of associated ideas (1966, p. 160). Correspondingly, a shift in meaning can involve change in associated ideas, change in reference and/or change in use. On these grounds, Hesse gets close to dissolving the literal/metaphorical distinction: "the two systems are seen as more like each other; they seem to interact and adapt to one another, even to the point of invalidating their original literal descriptions if these are understood in the new, postmetaphoric sense" (1966, p. 162); see also Hesse (1983). The crucial point is that metaphors can (in spite or because of this) be used to communicate reliably and are not purely subjective and psychological. Not "*any* scientific model can be imposed a priori on *any* explanandum and function fruitfully in its explanation" (1966, p. 161). Scientific models, in contrast to poetic metaphors, have to subject to certain objective criteria, or as Hesse puts it, "their truth criteria, although not rigorously formalizable, are at least much clearer than in the case of poetic metaphor" (1966, p. 169). Correspondingly, one may "[speak] in the case of scientific models of the (perhaps unattainable) aim to find a 'perfect metaphor,' whose referent is the domain of the explanandum" (1966, p. 170). In my formulation, a model is evaluated with regard to whether it provides access to a phenomenon and matches the available empirical data about the phenomenon reasonably well.

Rom Harré and his co-authors also discuss models and metaphor together. They claim that both could be interpreted successfully with the same tool, namely their type-hierarchy approach (Aronson et al. 1995, p. 97). Yet, the role of metaphor in science is different (Harré, 1960, 1970, p. 47; Martin and Harré, 1982). According to Martin and Harré (1982), metaphorical language is used in the sciences to fill gaps in the scientific ordinary language vocabulary. Examples are metaphorical expressions that have acquired very specific interpretations, like *electric field*, *electric current* or *black hole*, which is why they should be understood "without the intention of a point-by-point comparison" (Martin and Harré, 1982, p. 100). Such metaphorical terms can, however, be viewed as a "spin off" of scientific models (1982, p. 100). Martin and Harré (1982, p. 100) explain:

> The relationship of model and metaphor is this: if we use the image of a fluid to explicate the supposed action of the electrical energy, we say that the fluid is functioning as a model for our conception of the nature of electricity. If, however, we then go on to speak of the "rate of flow" of an "electrical current", we are using metaphorical language based on the fluid model.

It seems that many examples lend force to the view that metaphorical scientific terminology, even if hardly recognizable as such any longer, can be a "spin off" of models (without the claim that models themselves are metaphorical) and I shall discuss one example below. That Martin and Harré, different from myself, consider models simply as analogues has no bearing on this specific point.

## Metaphorical Models

I now single out the features of models discussed in association with the claim that scientific models are metaphors. The listed points presuppose that the metaphors in question are connected to analogies and that something like the cognitive claim attached to the interaction view holds.

### *Familiarity and understanding*

Models and metaphors exploit the strategy of understanding something in terms of something else that is better understood and more familiar; they exploit the analogy relationship suggested by a metaphor or explored in a model. Of course, being familiar does not equate with being understood, but familiarity can be a factor in understanding. This is also not to suggest that understanding can be reduced to the use of analogy, but having organized information in one domain (source) of exploration satisfactorily can help to make connections to and do the same in another domain (target). The aim is to apply the same pattern in the target domain as in the source domain, with the same assumptions of structural relationships in both the source and the target domains. For instance, to think of the energy generation process in quasars in terms of energy generation in binary stars is helpful because it was by studying binary star systems that the importance of





accretion of mass as a power source was first recognized. Moreover, turning the gravitational energy into the "internal" energy of a system is perhaps the only way to account for the enormous energies that must be present in quasars. The proposed conversion process of gravitational energy is, in turn, inspired by disks in planet or star formation. Piecing together these ideas based on analogies to already better-analyzed empirical phenomena paved the way to the formulation of the accretion disk model that is constitutive in explaining energy present in quasars and radio galaxies. For more examples, see Cornelis (2000).

### *Material for exploration*

Models and metaphors can be hypothetical and exploratory. Besides a positive analogy which may have given rise to the formulation of a model or metaphor, there are negative and neutral analogies that can be explored. This exploration furthers creative insight, as the interaction view proposes, because sometimes negative and neutral analogies offer a pool of ideas of what can be tested about the target domain. Metaphorical models nevertheless have to stand up to empirical reality, which is why Hesse talks about "clearer truth criteria than for poetic metaphors" and "the (perhaps unattainable) aim to find a 'perfect metaphor'" (1966, p. 170), i.e. a perfect description, one that provides an empirically adequate description of a phenomenon. An example for metaphorical exploration is artificial neural networks as used in computing for pattern recognition. Digital computers are serial processors and good at serial tasks such as counting or adding up. They are less good at tasks that require the processing of a multitude of diverse items of information, tasks such as vision (a multitude of colors and shapes etc.) or speech recognition (a multitude of sounds) at which the human brain excels. The example of the brain demonstrates how to cope with such tasks through many simple processing elements that work in parallel and "share the job." This makes the system tolerant to errors; in such a parallel distributed processing system, a single neuron going wrong has no great effect. The idea of artificial neural networks was therefore to transfer the idea of parallel processing to the computer so as to take advantage of the processing features of the brain. Moreover, the assumption that learning occurs in the brain when modifications are made to the effective coupling between one cell and another at a synaptic junction is simulated in artificial systems through positive or negative reinforcement of connections. Artificial neural networks produce impressive results in pattern recognition, even though there remain considerable negative analogies between them and the human brain. Not only do the number of connections differ hugely from the brain, but the nodes in artificial neural networks are highly simplified in comparison to neurons in the brain. Explaining the neural network metaphor involves becoming aware of its appropriate applications as well as its limits.

### *Coping with negative analogies*

Metaphors, analyzed as being connected to analogies, usually involve the statement of negative analogies; these do not tend to hinder the use of the metaphor, however. Scientific models, in contrast, require attention to so-called negative analogies. Even though models claim no more than to be partial descriptions, to use them efficiently, their users need to be aware of the negative analogies, those "things" not described by the model and that do not stand up to empirical tests. Knowing what the model is not a model of is part of the model. As shown, an artificial neural network does not simulate the structure of the human brain in every respect, but we need to know in what respectsit does. Not spelling out disanalogies explicitly in a model can have detrimental effects. Some metaphors, especially if even the positive analogy is questionable, can be positively misleading, e.g. the common interpretation of entropy as a measure of disorder. Consider the example of a partitioned box of which one half contains a gas and the other is empty. When the partition is removed, the gas spreads over both halves of the box. This constitutes an increase of entropy because it is extremely unlikely that all gas molecules will ever return to one half of the box spontaneously. It is not intuitive why the second situation should be viewed as a state of higher disorder than the first; a more precise way of modeling entropy is to talk about the number of available microstates per macrostate. For some examples from chemistry, see Bhushan and Rosenfeld (1995).

### *New terminology*

Metaphorical models are "new vocabulary" in terms of which empirical data can be described. This "vocabulary" makes possible a description intended to provide interpretations of data. In a narrower sense of a vocabulary, metaphorical terminology is employed to meet the problem of catachresis, i.e. to provide scientific terminology where none existed previously (Boyd, 1993). Sometimes, such new terminology has its root in the analogues that inspired the formulation of the model to which the terminology belongs (a "spin off" of the model); Martin and Harré (1982). An example of this is simulated annealing, a method used in optimization for determining the best fit parameters of a model based on some data. The physical process of annealing is one in which a material is heated to a high temperature and then slowly cooled. This process increases the chance that the material relaxes to a low energy state rather than getting stuck in a higher energy metastable state. Annealing is about avoiding "local minima" of energy states so as to reach the "global minimum." Having found a local minimum, it may be necessary to expend some energy first, i.e. to "climb over" an "energy mountain," to find a more global minimum, the low energy state. This can be interpreted to correspond to finding an "optimal fit" in the search for the best fitting parameters





for a data model; one wants to avoid terminating the search early at what seems a good fit in a local search area. In the computational method of simulated annealing, not only the equations from statistical physics, such as the Boltzmann equation, are adopted almost exactly, but the descriptive terminology is also taken over. Terms such as ***temperature***, ***specific heat capacity*** and ***entropy*** are applied to optimization in a meaningful way.

### *Literal versus metaphorical*

Finally, the converse of the metaphor claim needs to be considered briefly: What would "being literal" mean in the context of scientific modeling? What would be the consequences of a literal–metaphorical distinction for scientific models if they are, as the claim goes, metaphors? In the context of science, this would presumably mean that there are "proper," "precise" or "literal" ways of describing an empirical phenomenon and other, metaphorical and less direct ways, the latter being exemplified by scientific models. One would then have to ask what "literal" ways of describing empirical phenomena are. Of course, there may just not be any alternative description for certain phenomena, e.g. for "electron spin," although this is what talk about literal and metaphorical language implies. One answer that may be put forward by some is that ***theories*** are the literal descriptions. However, theories cannot range as an alternative to models, if, as my claim goes, they are not descriptions of phenomena (Cartwright, 1999). Instead, theories may be employed in models and applied to empirical phenomena only ***through*** scientific models. In this case they cannot be viewed as an independent mode of description of phenomena, i.e. as literal in contrast to models that are metaphorical.

## Current Issues

There is a range of general issues concerning scientific models which I have barely covered. These include how models work, why they are needed and to what extent they are used. Other issues are, for instance, how models relate to theories or whether simulations are models. Yet, in this last section, I want to focus only on points that are specifically raised in the context of comparing scientific models with metaphors.

### *Creativity*

Employing metaphors can sometimes be a creative use of language, both in formulation and interpretation. Consequently, explaining human creativity, in science and elsewhere, is a common agenda of those seeking to know how metaphor works. Metaphor is a popular answer to any exploration of creativity, but it is also a fairly impenetrable keeper of its secret because it is not so easily analysed itself. Especially in the light of metaphorical models, I wonder whether one ought not dispel the opinion that metaphors are formed by sudden strikes of genius. (Note that this would, in any case, only apply to new metaphors on first use, not on the vast number of worn and trite specimens.) Certainly the majority of scientific models are developed by laborious and continued efforts that stretch over years and require enormous endurance on the side of those who seek these results (Bailer-Jones, 2000a). Ingenuity does not equate with effortlessness, and progress often occurs in very small steps. Correspondingly, one should examine the thesis that metaphors also only gradually become widely accepted and uniformly understood, just like scientific insight rarely strikes scientists out of the blue. In any case, it is worth challenging the myth of sudden, inexplicable insights in science that is often associated with creativity-generating metaphor (e.g. Kekulé's notorious dream of the snake biting its tale leading him to the conception of the six-carbon benzene ring). Creativity in science deserves to be investigated in its own right, and not only in the framework of metaphor; see issues 4-3 and 4-4, 1999, of *Foundations of Science* on Scientific *Discovery and Creativity.*

### *Acquisition of new meaning*

Formulating a metaphor is about gaining a "newish" expression connected with a "newish" description of interpretation of a subject matter. "Newish" is supposed to take account

(a) of a gradual development of metaphorical expressions, and
(b) of those aspects of the expression that are familiar by way of the analogue which the metaphor exploits.

The interaction view proposes something like a sudden discovery of a new metaphor ensued possibly by a gradual shift in meaning of the primary and the secondary subject in response to that discovery. The implication is that the metaphorical expression is likely to give up one meaning and slowly to acquire another. However, even if we now talk about electric currents or artificial neural networks, we have not lost the capacity of using "current" to describe a river or "neural network" to describe neurons connected in the brain. Expansion of the domain of application can be observed because the expression now occurs metaphorically, but the use of the expression in its source domain need not disappear. Whether talk is about electric fields or ploughing a field, both are understood equally well, and there is no obvious reason why metaphor should function differently from literal language use in describing (Rothbart, 1984; Machamer, 2000). At some point, "field" has obviously acquired an additional meaning that





permits it to be applied in the context of electromagnetism. Understanding it is a matter of working out which meaning a term happens to have in which context. Similarly, ideas for models can be employed in different domains: models of statistical mechanics do not disappear because they have a new application in the technique of simulated annealing. Yet, even if one denies a fundamental difference between literal and metaphorical language, questions remain about how we succeed in the complex task of interpreting linguistic expressions, picking among the range of possible interpretations in view of context and associations. For scientific models, this means that even when we surmount viewing them as either literal or metaphorical, we still need to examine how precisely they provide information about the empirical world.

### *Metaphorical models and metaphorical terminology*

In future work, it is essential to distinguish carefully whether it is a model as a whole that is portrayed as metaphorical or whether it is merely a case of metaphorical ordinary language being used in describing a model (metaphorical or not), or both. Several different combinations seem possible, and it remains to be examined what effect these different levels of metaphorical penetration have on scientific thinking:

- Certain models are considered metaphorical in the sense that a transfer from one domain to another has taken place, but where no specific metaphorical terminology is used in this model, e.g. Bohr's model of the atom.
- In other cases, a structural relationship is made out between two domains that warrants a transfer leading to the formulation of a model in the target domain. In addition, this transfer gives rise to metaphorical language use accompanying the use of the model, e.g. *temperature* in simulated annealing or *noise* in observational astronomy.
- Then there are models where the descriptive terminology employed is metaphorical, but the two domains involved in this metaphorical terminology are not related in structure. An example is gravitational lensing. All a gravitational lens has in common with an optical lens is that it bends a light ray. The *bending* of a light ray due to gravitation is, unlike the case of an optical lens, not interpreted in terms of the optical phenomenon of refraction, so the metaphor is not connected to any deeper structural analogy between gravitational and optical lenses.
- Finally, yet other scientific metaphors that can be found in popular culture are without impact on scientific modeling which is why they can be disregarded for the current purposes. Examples are *litmus tests* in politics, a *critical mass* of participants needed before ideas can be *generated*, a military *nerve centre*, learning by *osmosis*, being *tuned in* or *turned off*, somebody being an Elvis *clone*, etc. (Hutchinson and Willerton, 1988).

*The relationships between models, metaphors and analogies*

I briefly recapitulate the connections between scientific models, metaphors and analogies to highlight the central research question resulting from their confrontation.

A model is an interpretation of an empirical phenomenon. As such, it is a description, although a partial description not intended to cover all aspects of the phenomenon in question, just like metaphors are, although the latter need not be interpretations. The task of scientific models is to facilitate (perceptual as well as intellectual) access to phenomena. While metaphors may also facilitate access to phenomena, their main characteristic is not this, but a transfer of at least one part of an expression from a source domain of application to a target domain. The implication is that the use of the expression in the source domain may be more familiar and/or better understood than its use in the target domain. Some scientific models can be analyzed as metaphors because their formulations involve a transfer of conceptions from a different domain (artificial neural networks, simulated annealing, Bohr's model of the atom). However, such a transfer is only of interest in the context of models insofar as it assists the purpose of the model, namely to interpret an empirical phenomenon.

Insightful metaphors are those that point to an analogy between phenomena of two different domains. The development of scientific models also often relies on analogies. Both the interpretation of models and that of metaphors frequently benefits from the analogies associated with them. Analogy deals with resemblances of attributes, relations or processes in different domains, exploited in models and highlighted by metaphors. Note that neither metaphors nor models *are* analogies – they are descriptions. This raises the question whether, at the cognitive level, there is anything involved in the metaphor claim concerning scientific models that can *not* be reduced to analogy. Is there something, e.g. the importance of context or associations, that lifts the cognitive force of metaphor above that of analogy? Much of this question seems to rest on not only the study of analogy, but also on whether there exist alternative strategies for knowledge formation.

To summarize, neither metaphors nor models are mysteriously creative or otherwise mysterious in how they contribute to our thinking about phenomena, although this is not to suggest that we understand everything about metaphor or about scientific modeling. Both can be, and need to be, however, subject to research. Many cognitive and creative claims about metaphors and metaphorical models appear reliant on the relationship of analogy, but whether analogy really deserves to be considered as the base category in developing interpretative descriptions equally requires further investigation. Finally, beyond the commonalties of scientific models and metaphor already highlighted, there is one other: scientific models appear to be, contrary to past research traditions, as central in scientific practice for describing and communicating aspects of the empirical world as metaphors are in ordinary language.





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## Notes

1 Mellor (1968) argues that Campbell requires analogy largely to overcome the abyss between theory and observation, and that, were it not for Campbell's strict theory–observation distinction, his account would not differ significantly from Duhem's.

2 "Analogy" refers to the relationship between two objects; an "analogue" is the object itself that is seen to be in the relationship of analogy to something.

3 This claim put forward very carefully is later reaffirmed: "I still wish to contend that some metaphors enable us to see aspects of reality that the metaphor's production helps to constitute" (Black, [1977] 1993, p. 38).

4 Black ([1977] 1993, p. 30) later contends: "I am now impressed, as I was insufficiently when composing *Metaphor*, by the tight connections between the notions of models and metaphors. Every implication-complex supported by a metaphor's secondary subject, I now think, is a *model* of the ascriptions imputed to the primary subject: Every metaphor is the tip of a submerged model."

## References

Achinstein, P. (1968): *Concepts of Science.* Baltimore, Maryland: John Hopkins Press.

Aronson, J. L., Harré, R. and Way, E. C. (1995): *Realism Rescued: How Scientific Progress is Possible.* Chicago, Illinois: Open Court.

Bailer-Jones, D. M. (2000a): "Modeling Extended Extragalactic Radio Sources," *Studies in History and Philosophy of Modern Physics*, 31B, 49–74.

Bailer-Jones, D. M. (2000b): "Scientific Models as Metaphors," in F. Hallyn (ed.), *Metaphor and Analogy in the Sciences*, Dordrecht: Kluwer Academic Publishers, 181–98.

Bhushan, N. and Rosenfeld, S. (1995): "Metaphorical Models in Chemistry," *Journal of Chemical Education*, 72, 578–82.

Black, M. (1954): "Metaphor," *Proceedings of the Aristotelian Society*, 55, 273–94.

Black, M. (1962): *Models and Metaphors.* Ithaca, New York: Cornell University Press.

Black, M. ([1977] 1993): "More about Metaphor," in A. Ortony (ed.), *Metaphor and Thought*, Cambridge: Cambridge University Press, 19–41.

Boyd, R. (1993): "Metaphor and Theory Change: What is 'Metaphor' a Metaphor for?" in A. Ortony (ed.), *Metaphor and Thought*, Cambridge: Cambridge University Press, 481–532.

Bradie, M. (1998): "Models and Metaphors in Science: The Metaphorical Turn," *Protosociology*, 12, 305–18.

Bradie, M. (1999): "Science and Metaphor," *Biology and Philosophy*, 14, 159–66.
Campbell, N. R. ([1920] 1957): *Foundations of Science* (formerly titled: *Physics, The Elements*). New York: Dover Publications.
Cartwright, N. (1999): *The Dappled World.* Cambridge: Cambridge University Press.
Cornelis, G. C. (2000): "Analogical Reasoning in Modern Cosmological Thinking," in F. Hallyn (ed.), *Metaphor and Analogy in the Sciences*, Dordrecht: Kluwer Academic Publishers, 165–80.
Davidson, D. ([1978] 1984): "What Metaphors Mean," in *Inquiries into Truth and Interpretation*, Oxford: Clarendon Press, 245–64.
Duhem, P. ([1914] 1954): *The Aim and Structure of Physical Theory.* Translated from the French 2nd edn, Princeton, New Jersey: Princeton University Press.
Falkenhainer, B., Forbus, K. D. and Gentner, D. (1989): "The Structure-Mapping Engine: Algorithm and Examples," *Artificial Intelligence*, 41, 1–63.
Gentner, D. (1982): "Are Scientific Analogies Metaphors?" in D. S. Miall (ed.), *Metaphor: Problems and Perspectives*, Sussex: The Harvester Press, 106–32.
Gentner, D. (1983): "Structure Mapping: A Theoretical Framework for Analogy," *Cognitive Science*, 7, 155–70.
Gentner, D. and Markman, A. B. (1997): "Structure Mapping in Analogy and Similarity," *American Psychologist*, 52, 45–56.
Giere, R. (1999): *Science Without Laws.* Chicago: University of Chicago Press.
Harman, P. M. (1982): *Energy, Force and Matter.* Cambridge: Cambridge University Press.
Harman, P. M. (1998): *The Natural Philosophy of James Clerk Maxwell.* Cambridge: Cambridge University Press.
Harré, R. (1960): "Metaphor, Model and Mechanism," *Proceedings of the Aristotelian Society*, 60, 101–22.
Harré, R. (1970): *The Principles of Scientific Thinking.* London: Macmillian.
Harré, R. (1988): "Where Models and Analogies Really Count," *International Studies in the Philosophy of Science*, 2, 118–33.
Hesse, M. (1953): "Models in Physics," *British Journal for the Philosophy of Science*, 4, 198–214.
Hesse, M. (1966): *Models and Analogies in Science.* Notre Dame: University of Notre Dame Press.
Hesse, M. (1967): "Models and Analogy in Science," in P. Edwards (ed.), *The Encyclopedia of Philosophy*, New York: Macmillian, 354–9.
Hesse, M. (1983): "The Cognitive Claims of Metaphor," in J. P. van Noppen (ed.), *Metaphor and Religion*, Brussels: Study Series of the Vrije Universiteit Brussel, 27–45.
Hofstadter, D. (1995): *Fluid Concepts and Creative Analogies.* London: Penguin.
Holyoak, K. and Thagard, P. (1989): Analogical Mapping by Constraint Satisfaction," *Cognitive Science*, 13, 295–355.
Holyoak, K. and Thagard, P. (1997): "The Analogical Mind," *American Psychologist*, 52, 35–44.
Hutchinson, B. and Willerton, C. (1988): "Slanging with Science," *Journal of Chemical Education*, 65, 1048–9.
Hutten, E. (1954): "The Role of Models in Physics, "*British Journal for the Philosophy of Science*, 4, 284–301.
Kittay, E. F. (1987): *Metaphor. Its Cognitive Force and Linguistic Structure.* Oxford: Clarendon.





Lakoff, G. (1993): "The Contemporary Theory of Metaphor," in A. Ortony (ed.), *Metaphor and Thought*, Cambridge: Cambridge University Press, 202–51.
Lakoff, G. and Johnson, M. (1980): *Metaphors We Live By.* Chicago: University of Chicago Press.
Lakoff, G. and Johnson, M. (1999): *Philosophy in the Flesh: The Embodied Mind and Its Challenge to Western Thought.* New York: HarperCollins Publishers.
Langacker, R. W. (1987): *Foundation of Cognitive Grammar. Vol. 1: Theoretical Prerequisites.* Stanford, California: Stanford University Press.
Leatherdale, W. H. (1974): *The Role of Analogy, Model and Metaphor in Science.* Amsterdam: North Holland.
Machamer, P. (2000): "The Nature of Metaphor and Scientific Descriptions," in F. Hallyn (ed.), *Metaphor and Analogy in the Sciences*, Dordrecht: Kluwer Academic Publishers, 35–52.
Martin, J. and Harré, R. (1982): "Metaphor in Science, in D. S. Miall (ed.), *Metaphor*, Sussex: The Harvester Press, 89–105.
Mellor, D. H. (1968): "Models and Analogies in Science: Duhem *versus* Campbell?" *Isis*, 59, 282–90.
Miller, A. (1996): *Insights of Genius.* New York: Springer-Verlag.
Morgan, M. and Morrison, M. (eds.) (1999): *Models as Mediators.* Cambridge: Cambridge University Press.
Nagel, E. ([1960] 1979): *The Structure of Science.* Indianapolis, Indiana: Hackett Publishing Company.
North, J. D. (1980): "Science and Analogy," in M. D. Grmek, R. S. Cohen and G. Cimino (eds.), *On Scientific Discovery*, Boston Studies in the Philosophy of Science, Dordrecht: D. Reidel Publishing Company, 115–40.
Paton, R. C. (1992): "Towards a Metaphorical Biology," *Biology and Philosophy*, 7, 279–94.
Richards, I. A. (1936): *The Philosophy of Rhetoric.* New York: Oxford University Press.
Rothbart, D. (1984): "The Semantics of Metaphor and the Structure of Science," *Philosophy of Science*, 51, 595–615.
Rumelhart, D. E. ([1979] 1993): "Some Problems with the Notion of Literal Meanings," in A. Ortony (ed.), *Metaphor and Thought*, Cambridge: Cambridge University Press, 71–82.
Searle, J. (1979): *Expression and Meaning.* Cambridge: Cambridge University Press.
VanLehn, K. (1998): "Analogy Events: How Examples Are Used During Problem Solving," *Cognitive Science*, 22, 347–88.