

## What makes a good metaphor in science?

*O que faz uma boa metáfora na ciência?*

**Sergio Fernando Martínez Muñoz**

Universidad Nacional Autónoma de México – UNAM – Cidade do México – México

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**Abstract:** Metaphors have mainly been discussed and studied as rhetorical devices in human communication and in literary studies. In philosophy and science, metaphors have been considered important as heuristic tools, for aesthetic embellishment, or in helping communicate complex ideas more simply; but as having no epistemic force. Philosophers and scientists are cautioned to avoid metaphors as explanatory resources. However, I present several examples where metaphors have played a significant role in the advancement of scientific knowledge and not as mere heuristic aids or decoration. This tension is worth addressing. I use recent work in the cognitive sciences to argue that some metaphors play a significant role organizing and coordinating scientific practices in relation to goals of inquiry, thereby promoting epistemic values (scientific explanations and more generally, understanding) in the process. Such metaphors therefore perform a key cognitive role. Good metaphors in the epistemic sense, then, are those that play such a cognitive role.

**Keywords:** scientific metaphor; metaphor and scientific reasoning; scientific metaphors as norms.

**Resumo:** As metáforas têm sido discutidas e estudadas principalmente como dispositivos retóricos na comunicação humana e nos estudos literários. Na filosofia e na ciência, as metáforas foram consideradas importantes como ferramentas heurísticas, para embelezamento estético ou para ajudar a comunicar ideias complexas de forma mais simples; mas não como tendo força epistêmica. Filósofos e cientistas são advertidos a evitar metáforas como recursos explicativos. No entanto, apresento vários exemplos em que as metáforas têm desempenhado um papel significativo no avanço do conhecimento científico e não como meras ajudas heurísticas ou decorativas. Vale a pena abordar essa tensão. Eu uso trabalhos recentes nas ciências cognitivas para argumentar que algumas metáforas desempenham um papel significativo na organização e coordenação de práticas científicas em relação aos objetivos da investigação, promovendo assim valores epistêmicos (explicações científicas e, de maneira mais geral, compreensão) no processo. Tais metáforas, portanto, desempenham um papel cognitivo fundamental. Boas metáforas no sentido epistêmico, então, são aquelas que desempenham tal papel cognitivo.

**Palavras-chave:** metáfora científica; metáfora e raciocínio científicos; metáforas científicas como normas.

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## 1 Introduction

Everyday language is full of metaphors. When someone says that John is an early bird, or when you talk about the force of an argument or of a key idea, you are using metaphors. However, how to characterize metaphor is a controversial issue since it involves assumptions as to what language is, what cognition is, and assumptions about what it is that makes a metaphor a good (or a bad) one. In everyday language and poetry, we can develop norms that, even if ambiguous or subject to different interpretations, are widely accepted in specific contexts (at a given time). But the question is, why do philosophers and scientists often reject that something similar can be asserted of scientific metaphors in relation to epistemic values? Aristotle regarded metaphor highly, yet he famously argued that, although metaphor can be very important in all linguistic communication and its mastery is a mark of genius in poetry, metaphors should not be used in philosophy or in scientific language. There is an obvious motivation for this view. Because Aristotle viewed scientific/philosophical reasoning as structured in deductive arguments (in his theory of the syllogism), metaphors and analogies could only play a derivative or heuristic role. For Aristotle, and in general for the traditional “comparison view”, the key role of a metaphor relies on its formulation of analogical comparison. A metaphor is converted into a simile and is then interpreted by comparing the respects in which two things are similar. Thus, the perception of similarity is the basis of its use and understanding. Since this relation of similarity cannot be reduced to deductive reasoning, it follows that metaphors should be kept away from scientific reasoning.

Throughout the history of philosophy, major philosophers have issued constant warnings about the perils of metaphor by appealing, albeit belatedly, to the assumption that the paradigm of scientific reasoning is deductive reasoning. Plato’s critique of the sophists is mainly a critique of the use of ambiguous words in philosophical discussions.

Hobbes considers metaphors dangerous to the development and propagation of scientific and political knowledge. Locke advises us to “strip” the superfluous ideas evoked by metaphors and to focus only on the ideas on which the argumentation hinges. Metaphors, says Locke (1690), lead us astray by moving the passions and misleading judgement. For Locke (1690), thought has to rely on simple ideas, obtained through direct sense impressions. Only this reliance on simple ideas can lead to the “Order and Clearness” distinctive of good philosophy. Locke’s shadow reaches as far as logical empiricists in the 20th century.<sup>1</sup>

Black (1962) proposed an important and influential philosophical theory of metaphor: his “interaction theory” of metaphor rejected the possibility of reducing the content of metaphors to a non-metaphorical (literal) language. Black (1962) asserted that a metaphor relates the common-places we associate with what he calls “the primary system”, in which metaphor is used, and the secondary system, in which the word is literal. Metaphor draws our attention to specific features of the secondary system which lead us to view the primary system in a different way. The metaphor changes the meaning of both, the primary and the secondary system, and thus, the metaphor cannot be translated into literal language without cognitive loss. When we talk of the atom as a miniature solar system, we change the meaning of “solar system” as well as the meaning of “atom”. Black (1962) thinks however, that it is not possible to explain what a good metaphor is, or what makes a metaphor a good one. Similarity for Black (1962) is suspect and “cannot ground a criterion for what a good metaphor is in general, and in particular in science”. This rejection

<sup>1</sup> There are of course eminent exceptions. In the 18th century, Condillac (1746) argued that all language was metaphorical. I.A. Richards (1924), a literary critic influential in the philosophical discussion about metaphors in the first part of the 20th century, famously argued that it is not mere embellishment. The basic reason for this, says Richards, is that thinking involves sorting (recognitions) which only later lead us to identify particulars. A word or phrase refers to two different things, and since this dual reference involves thinking (and in particular the past experience required for the recognitions in question), metaphor is indispensable in thought. The conclusion then is not only that all language is metaphorical, but that all thought is expressed by means of linguistic metaphors. Condillac (1746), Richards (1924), and other eminent philosophers who expressed similar views (like Frederick Nietzsche), were not interested in the question we focus on in this paper.

of similarity in relation to metaphors has led not only philosophers but scientists to warn their colleagues about relying on metaphors.

The problem with such a view is that, as we show next, the sciences do seem to have criteria allowing us to distinguish good metaphors from bad, and the history and philosophy of science clearly show that metaphors play a constitutive role in many theoretical developments. Still, the rejection of the role of metaphors in the growth of scientific understanding is widely shared by many scientists and philosophers. How can we explain, or overcome, this tension between what the scientists do and what the scientists (and philosophers of science) often say?

## 2 Metaphors in the History of Science

Natural philosophy from the late 17th century onward developed an increasing distance from alchemy, but for centuries alchemy was seen as something akin to science. Newton famously dabbled in Alchemy and related practices with enthusiasm. Alchemists constructed theories of nature based on metaphors which were related to one another and connected in webs of metaphorical meaning. The basic metaphor was that of macrocosm/microcosm, according to which there was a fundamental correspondence between man (the microcosm) and the natural world. But many other metaphors elaborated on this basic one. Therefore, the pervasive use of metaphors, and even mutual dependence, was no different between alchemy and science.

The publication of Robert Hooke's landmark book *Micrographia* is an excellent example of the role of metaphors not only in spreading but also in articulating scientific knowledge. Hooke (1665) did not invent the microscope, nor was he the first to make drawings of what you could see under a microscope. But he was an accomplished graphic artist, knowledgeable in printing techniques. The book was intended to appeal to the general public (and the King in particular, who had indirectly entrusted the work) (JACK, 2009). Maybe the most famous image in the book is the drawing of a flea. To see what could not

be seen without the help of the microscope certainly had a major impact on recognizing the importance of the kind of knowledge about things that we cannot see with the naked eye. The image of the flea is a powerful metaphor.

In the sense that the image of a flea stands for the whole microscopic world it is a metonymy, but the image of the flea is also a metaphor in the sense that the image opens the possibility of a new kind of knowledge, of a new world materially anchored in the microscope (and more generally in scientific instrumentation and methods).<sup>2</sup>

Hooke (1665) described a slice of cork as made of structures which he called cells because they resembled honeycomb cells. Hooke (1665), however, did not merely describe; he argued that the cells he had found explained the cork's properties. These characteristics of cork not only made it useful for different purposes (such as bottling wine), but also gave him the idea that fossils were remains of previously existing organisms. The discovery of a microscopic world had to have implications for advancing our understanding of the macroscopic world. Terms like cell were clear metaphors (or analogies, if you like) which were indeed ambiguous, but nonetheless conveyed understanding of the sort of reality the microscope allowed us to see. The pores in the cork were also described as "pipes" through which the juices of vegetables are transported and thus suggested the importance of such "cells" in the structure of living beings. One could say that Hooke's "cells" were proto-theoretical terms.

There were many other metaphors that played a key role in Hooke's narrative. The use of the term "pump" to refer to the part of a fly "whereby these creatures might exercise their analogous lungs" (HOOKE, 1665) pointed to a metaphor which was already in use and well known among philosophers because of Harvey's metaphor of the heart as a pump. Hooke (1665) talked of a flea's "armor", of

<sup>2</sup> As Jensen and Greve puts it in Wiben and Greve (2019): "Metaphor, the human tendency to enact doubleness, to see, feel, experience, and understand one kind of thing in terms of another can also be seen as stemming from perceived invariances in the environment and not chiefly from mental operations of cross-domain mappings".

seeds as “little automatons”, of the “levers” of insects’ legs, and referred to the needle-like structures observed in the leaves of stinging nettles as “syringes” (JACK, 2009). He also talked of God as a master craftsman who had designed the whole of nature in the most minute detail. The mechanical philosophy and natural theology fitted together nicely via such metaphors.

The difference between alchemy and “science” is not simply a difference in the use of metaphors, as this discussion shows. Nor is the use of the experimental method per se a key difference. Alchemists were very good experimenters; it was a fairly common task for them. What ends up differentiating the alchemists’ method from that of natural philosophers is that for philosophers, metaphors, technologies, values and narratives go hand-in-hand towards the characterization of a mechanical world view grounding a view of nature and of human beings promoting norms of behavior and of organization of social life.<sup>3</sup>

### 3 Metaphors in contemporary science

Metaphors are everywhere in contemporary science. In some sciences, like mathematics, they can be so out of sight that mathematicians learn to think of their discipline as free from metaphors. But not even mathematics is free from metaphors. Van Bendegem (2000) argues for the essential role of metaphors not only in the history of mathematics but in contemporary mathematics. He shows that metaphors in mathematics are tools for understanding. To appreciate his arguments would require us to introduce ideas which will need too much space. In this section, I would rather give examples of the contributions of metaphors to the norms of scientific inquiry in biology and the social sciences.

Biologists talk of “genetic blueprints”, “molecular clocks”, “food chains”, “missing links” and so on. Many biologists criticize the use of metaphors because they are ambiguous and promote confusion

<sup>3</sup> Metaphors often play the role of what Jack calls “pedagogies of sight”, which are metaphors used as norms promoting ways of seeing. (JACK, 2009)

and misunderstanding. Indeed, biology is full of discussions about terminology, which is often a debate about the right way of understanding a metaphor. Metaphors like “blueprint” invite a biological determinism which should be avoided, but the danger of misunderstanding should not lead us to think that ambiguity is the culprit. Ambiguity is an indispensable source of creativity and thus of new concepts, even if it can also be the cause of misinterpretations and sterile discussions. As Olson et al (2019) put it, metaphors (in biology) are here to stay, but we have to learn to work with them while trying to become conscious of their limitation. Indeed, this is good advice. Metaphors are part of the conceptual structuring of theories, bridging different disciplinary practices and goals and integrating them into a research project or a discipline. The ambiguity of metaphors affords the flexibility required to relate areas of knowledge which involve constant semantic changes and discussions about the right way of conceptualizing processes or phenomena. Biology is not an exceptional discipline in this regard. In contemporary economics, there are many discussions of the fundamental role of metaphors. For example, McCloskey (1983) has argued that (some) models in economics are non-ornamental metaphors and that “mathematical and non-mathematical reasoning in economics rely on Metaphor” (McCLOSKEY, 1983).

In the process of giving a panoramic view of the field of Ecolinguistics, Steffen and Fill (2014) say that this discipline should be seen as an archipelago more than a continent:

Hitherto, it has developed through insulated scientific programs that offer different views on both the language ecology and the theories and methods that are most appropriate for study. The variety is not just conceptual: from a sociological point of view, one is struck by lack of interaction between the schools that combine language and ecology (STEFFEN; FILL, 2014, p.16).

I would say that most scientific disciplines, particularly in the research-oriented areas involving new technology, fit this description. The use of metaphors as guides and norms for the advancement of scientific understanding is indispensable.

#### 4 Metaphors and the philosophy of science

The basic problem that philosophers have ascribed to a normative use of metaphor is the ambiguity and lack of precision involved. Black (1955) wrote a highly influential paper arguing for restraint in the use of metaphors in the sciences. Metaphors, he says, can only be thought of as heuristic devices since the semantic interaction between the figurative and the literal subjects are too imprecise and ultimately stated a non-existent relation. Another consideration might have led him to restrict the role of metaphors in science to heuristics. If scientific knowledge is assumed to be different from ordinary experience, precisely because of the role of fixed epistemic norms in its development (as contemporary logical empiricists did assume), then Black (1955) could maintain that all language was metaphoric, since this claim did not spill over to science. However, once logical empiricism is questioned as an account of the epistemic structure of science, any claim that the language of science can be sharply distinguished from the everyday language is seriously eroded. If there is no sharp distinction between the two languages, then the argument flounders—unless one claims that metaphors could have a significant epistemic role.

In hindsight, once logical empiricism started being questioned as a satisfactory philosophical account of science, the claim that the language of science is metaphorical should have been taken seriously and explored. The metaphoricity of scientific concepts could play a role in the dynamics and structuring of science. Indeed, while very few people realized the importance of this possibility during the years of heated debate around the “historicist turn”, Hesse (1963) did.<sup>4</sup>

Hesse (1963) recognized that the cognitive processes involved in the generation and stabilization of metaphors in science, as in everyday language, was far from understood, but taking scientific theories as “metaphorical redescrptions” was a step in the

right direction. Hesse (1963), following Black (1962), claims that metaphors redescribe a primary system in terms of a secondary system and thus both systems interact. But whereas for Black (1955), the semantics of metaphor consist in the study of the shifting meanings in both metaphor and context under the assumption that there is a distinction between literal language (normal descriptive terminology) and metaphorical language, this fundamental dichotomy is questioned by Hesse (1963). The implications of her claim that there is no normal descriptive terminology which is literal, stable and unequivocal, led her to a theory of language and a philosophy of science which, even if not taken seriously fifty years ago, is worth revisiting.

On several occasions, Hesse (1988) made it clear that an important function of metaphors is related to their role in the mediation between different kinds of knowledge, and in particular in the generation of inferences and abstract concepts which respond to questions posed in specific scientific practices reflecting social interests.

Metaphor does indeed mediate a kind of social knowledge - by its mechanism of emphasis and de-emphasis of similarities and differences, it provides evaluations reflecting social interests and judgments of significance. This is particularly the case with extended global metaphors: to view nature and man as intricate pieces of clockwork, to see societies as organisms or as arenas of class conflict, to interpret science as an instrument, or politics as a communication system; all these global metaphors redescribe experience in terms of some ordering of social values and interests (HESSE, 1988, p.8).

Contemporary cognitive science can be used to advance Mary Hesse’s basic idea that good metaphors in science are those that can be integrated into some ordering of social values and interests, and in particular those values leading scientific inquiry towards fruitful models and inferences.

#### 5 Our question in contemporary cognitive sciences

<sup>4</sup> Stephen Toulmin is another example. His views on the topic were mainly ignored by philosophers of science, and only taken seriously in theories of argumentation (SANTIBÁNEZ, 2010).

Gentner (1982) has published several papers starting in the 1980's addressing the problem we are interested in. In 1982, Gentner asks the question of what makes some analogies useful in science, but not others. She starts by recognizing that it is not enough to argue that good analogies make correct predictions, because, as she shows, good analogies sometimes make bad predictions. What she suggests is that the answer requires us to give a structural characterization of analogy in science.

Her proposal starts by distinguishing literal similarity from analogical relatedness. If we say that a hydrogen atom is like the solar system, the relationships correspond, but the objects do not. This is an example of analogical comparison. Analogical relatedness involves overlap of relationships; literal similarity, in addition, requires that the attributes of objects overlap.

Adopting this terminology, she proceeds to distinguish between expressive analogies, the sort of analogies used in literature, and the sort of explanatory analogies used in scientific reasoning. Explanatory analogy intends to explain, whereas expressive analogy intends to evoke or describe. Next, she distinguishes between good and bad explanatory analogies. She exemplifies a bad analogy with the comparison Paracelsus makes between metals and the solar system. He argues that Latin *Sol* (Sun) is gold and *Luna* (Moon) is silver. But this has no predictive value, since there is a lack of systematicity between the relations suggested by the analogy, starting with a lack of clarity about precisely which relations we should identify to start with.

By contrast, Gentner (1982) continues, in good scientific analogies, it is clear what the structure-mapping description is. For example, in the analogy of the solar system and the atom, the relation of attraction and the relation of rotation around the center are retained, and they play a role in the analogy, but the weight or other attributes of the systems involved do not. Once the structure serving as a frame for the comparison is fixed, Gentner (1982) proceeds to characterize what she considers to be the structural qualities of a good scientific analogy.

The key feature is the systematicity of the mapping, the degree to which the imported predicates from the base constitute a mutually constraining system. Mapping is systematic to the extent that any given predicate can be derived or at least partly constrained by the others (GENTNER, 1982, p.114). The Rutherford model is a highly systematic analogy. The imported relation of attraction, and that of orbiting, form a connected system with the key theoretical relation of the inverse square central force. This mutually constraining set of relations allows the derivation of other relations which would enrich the metaphor.

In summary, Gentner (1982) argues that complex scientific analogies can be psychologically characterized as cross-domain mappings of conceptual structure. This framework allows for the identification of the features that make a good explanatory metaphor. She acknowledges that her suggestion requires the elaboration of the psychological account, as well as more detailed study of how experts and novices proceed in reality.

Gentner (1982) thinks that metaphors and analogies can be characterized by the same kind of structure-mapping, but that metaphors are basically literary figures of speech, whereas analogies can be explanatory since they are typically higher in clarity and systematicity, though usually have less expressive power than the expressive analogies generally characterized as metaphors in literature. Gentner (1982) has continued to develop her thesis that metaphors can be characterized in terms of structure mappings and that such an account of metaphors can overcome the traditional rejection of criteria based on similarity. How one can distinguish different notions of similarity and develop a more sophisticated appreciation of similarity is part of what she calls "the career of a metaphor", a career which can be seen to be part of the development of individual human beings as well as of communities of inquiry (to use Dewey's famous concept).

Another way of approaching the importance of metaphors for the philosophy of science and, in particular, to answer our question of what makes a

good metaphor consists in showing the importance of metaphors in the development of abstract notions (theoretical terms and relational categories, for example) (ASMUTH; GENTNER, 2017). The exploration of this relation between metaphor and abstraction is an important line of research in psychology (JAMROZI ET AL, 2016) which allows the formation of criteria about what a good metaphor is. Using examples from the history of science, we show (CARILLO; MARTINEZ, 2022) how metaphors (via abstraction) play a role in the construction of epistemic criteria, guiding us to decide when a theory or a model is a promising scientific theory or model.

There are many other lines of research in the cognitive sciences providing resources to answer the question we posed at the beginning of the present paper. Johnson (2002), for example, argues that the best way to develop a satisfactory theory of attention in cognitive psychology is to appeal to those metaphors that determine how the phenomena of attention are identified. He is led to argue that metaphor-based value systems are characteristic of science. It would be in the context of a set of values shared by a community of inquirers that a metaphor would be considered a good metaphor.

## 6 Concluding Remarks

I have not given a precise answer to the question that is the topic of this paper. But as I hope it is by now clear, there is no single answer to the question. Once we abandon the idea that epistemic resources have to be well-defined and satisfy general criteria, the answer to the question of what makes a good metaphor in science has to start by characterizing with sufficient detail the context of the question, and then proceed to see what resources we have at our disposal to answer the question. Mary Hesse (1963; 1988) thought that one could give a rather general answer, in terms of what she calls a network theory of meaning. But this approach would not provide an answer to our question in a specific case. An answer to the question of what constitutes a good metaphor in specific cases requires a more

down-to-earth approach. We can try to characterize the psychological underpinnings of metaphors (for example, by identifying the structure of the cognitive constraints involved, as Gentner (1982) does), or the “material anchors” of the metaphor as we have suggested when discussing Hooke (1665) work, or as Nersessian (2015) has argued, an answer to our question requires approaching the problem from the perspective of cognitive practices and a methodology focusing on observational (ethnographic) studies conducted in naturalistic settings. For Nersessian (2015), the historical development of practices plays a key role in identifying the metaphors and the constraints and criteria develop in the process of consolidation of the practice, not only at the individual level but at the community level. This is what Nersessian (2022) calls a cognitive-historical analysis. In both cases cognitive and social constraints play a role. Taking into consideration the situated character of cognition (its “naturalistic settings”) seems to be a pre-condition for saying what makes a good metaphor in science.

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