Theodore L. Brown, ***Making Truth: Metaphor in Science***. Urbana: University of Illinois Press (2003), 232pp., $32.50 (cloth).

Making Truth is an engaging and well-written book about the importance of metaphor in science, intended for a wide audience. Theodore Brown, a chemistry professor, argues that metaphors are essential to every aspect of scientific activity: formulating hypotheses, interpreting observations, constructing models and explanations, and communicating with other scientists and with the public. Rather than presenting general philosophical arguments for this thesis, most of the book consists of detailed case studies, including some striking examples from molecular and cell biology. The scientific background is well explained, with plenty of helpful diagrams. A brief final chapter suggests some broad implications for the philosophy of science, science education, and the role of science in society. Brown denies that scientific knowledge is distinctively rational or objective, but he nevertheless attempts to find a middle ground between what he calls the "strongly objectivist" stance of many scientists and a "strongly social constructivist" stance.

The claim that metaphors or analogies are essential to scientific practice goes back to Hesse, who characterized theoretical explanation as "metaphoric redescription of the domain of the explanandum," though Hesse attributes an earlier version of the thesis to the physicist N. R. Campbell. There are two important ideas in this claim of essentiality. The first is that metaphors are semantically essential: the meaning of theoretical concepts cannot be grasped except through metaphors. The second is that metaphors are essential for making inferences that extend accepted theory. The crucial notion here is what Brown calls "metaphorical entailment," an inferential relationship between accepted knowledge and conjecture that is based upon a background metaphor.

That metaphors make a positive contribution to science in both of these respects seems undeniable, and Brown's case studies help to illustrate that they do. The book is full of examples that recount how metaphors have been introduced into scientific discourse and then elaborated into models (which are just extended metaphors, in Brown's view). What we do not find, however, is a clear analytical framework for understanding *how* metaphors fulfill their most important roles in science, or for evaluating them critically. There are no criteria proposed for assessing whether a particular claim is or is not "metaphorically entailed," or for taking a metaphor

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seriously to begin with. This deficiency may push Brown's picture closer to social constructivism than he would like. Before developing this point, though, let me review Brown's account of metaphor and explain what his case studies do accomplish.

The basic theory of metaphor, presented in two early chapters, is borrowed in large part from Lakoff and Johnson's book, *Metaphors We Live By*. As with others writing on this topic, Brown believes that to employ a metaphor is to apply concepts and information from one domain of experience (the *source domain*) to another (the *target domain*). When we speak of cell membrane 'channels', we are transferring ideas from our experience in the macroscopic world to make sense of something in the microscopic world, in this case the permeability of the membrane to certain ions. Following Lakoff and Johnson, Brown maintains that the target domain is typically accessible only through abstract models, i.e., metaphors. By contrast, the source domain is some feature of everyday experience of which we have "literal knowledge." Most commonly, we rely upon our individual "embodied experience" of macroscopic phenomena, as illustrated by 'ball-and-stick' models for chemical bonding or protein 'folding'. A second common resource, particularly in modeling complex interactions in chemistry or biology, is "social experience." Brown presents an excellent example here, the 'molecular chaperone': a protein that enables the formation of nucleosomes (chromosome constituents) by preventing "incorrect interactions" between histones (nucleosome components) and DNA.

The great virtue of confining ourselves to these two mundane varieties of source domain, in Brown's view, is the potential for bridging the gap between scientist and non-scientist. This is a theme on which Brown elaborates near the end of the book:

> When we recognize that scientific reasoning is based on the same kinds of thought processes used in other arenas of thought, that scientists are constrained in their attempts to read nature by the same embodied and social understandings that everyone uses to get along in life, science is really not so mysterious after all. (196)

Even conceding the prevalence of such metaphors, however, it is a mistake to be so restrictive about the choice of source domain. Given his broad characterization of metaphor, Brown should include any sophisticated analogy between two areas of scientific inquiry. Indeed, in one passage he writes that neural nets and genetic algorithms are grounded in "metaphors drawn from the biological sciences." Elsewhere, however, he holds firmly to the restrictive view. There is certainly some tension between the narrow thesis that all metaphors are grounded in everyday experience and a liberal definition that counts even highly sophisticated mathematical models as metaphors. Perhaps the theory of metaphor does offer promise for demystifying science, but not by quite so direct a route.

The main job of metaphors is to help us organize and interpret the "bare facts" of observation. Brown describes a host of metaphors employed in understanding the structure of complex molecules: space-filling models, lattices, cages, galleries, and folding. None of these metaphors, he notes, can be literal descriptions of the observed system. Rather, we interpret the data "as if" that system were a lattice, contained cages and so forth. Brown anticipates the objection that scientists function perfectly well despite either ignoring or barely acknowledging the importance of metaphors in their work. Still, he maintains that an appreciation of the metaphorical nature of models is critical for at least two reasons. First, despite their usefulness, metaphors must be taken with a grain of salt. Not every feature of the source domain is meant to be carried over, nor every feature of the target represented. A metaphor inevitably highlights certain features of the target and conceals others. Second, scientists can and usually do employ multiple metaphors in thinking about the same domain, each suited to different purposes.

This brings us to metaphorical entailment. The 'channel' metaphor already mentioned was first used to represent the fact that cell membranes are permeable to certain types of ions. The use of this metaphor, Brown observes, led naturally to the transfer of other attributes of macroscopic channels, such as boundary and shape, to the microscopic world of cell membranes. "The act of naming," he writes, "creates similarities" because of the metaphor's power to suggest questions and conjectures that direct experimental work.

Six chapters, the heart of the book, illustrate these ideas. Two chapters cover classical and modern models of the atom. Three chapters focus on models for simple and complex organic molecules, protein folding, and cellular-level metaphors. Finally, a chapter on global warming applies Brown's ideas about metaphor to a complex macroscopic system. The material on protein folding is particularly interesting. The principal metaphor explored in that chapter is the 'energy landscape', in which the process by which a protein settles into a stable, active form is compared to a marble rolling through a hilly landscape until it comes to rest. Brown explains why this metaphor is unsatisfactory: there are simply too many possible configurations to explore. A chain of one hundred amino acids folds in one second or less, but trying out all the possibilities would take longer than the age of the universe. A modified version of the metaphor, the 'rugged energy landscape', holds more promise. On this model, we restrict our attention to landscapes that resemble a single large funnel whose sides are punctuated with small jagged valleys. Protein molecules work their way down to the bottom in rapid stages, settling briefly into the small valleys as segments of structure are formed, and being jostled out again through interactions. The rugged landscape metaphor makes this model of protein folding available.

The strength of Brown's book lies in its detailed illustration of the *enabling* function of metaphors. Most, or perhaps even all, of our models and conjectures would not be possible without metaphors. As noted earlier, the main limitation of the book is that it provides no resources for the critical assessment of such conjectures. Brown tells us only that when it is appropriate to use a particular model or metaphor "is thus a matter of judgment and must be subjected to critical analysis in evaluating work that uses such metaphorical constructs." A second and related concern is that certain well-worn metaphors, such as the 'ball-and-stick' structures used to model chemical bonds, cease to carry the element of risk that Brown associates with all metaphors. As scientists come to learn which properties may and which may not be transferred, such metaphors or models may become almost as familiar as embodied experience.

These concerns become important when we turn to Brown's claims about the significance of metaphors for the philosophy of science. In his concluding chapter, Brown argues that accepting a metaphorical view of scientific theories makes it impossible to be a traditional scientific realist. Because of their dependence upon metaphor, scientific theories are forever "grounded in our embodied experiences;" they are human artifacts. They are also "products of the social context" in which the scientist works. Brown wants to resist extreme forms of social constructivism, arguing that even though the scientist's initial selection of metaphors is constrained by personal experience, the worked-out models must still stand up to experimental testing. That is a reasonable position, but it requires a more critical account of metaphorical reasoning.

Brown's objections to scientific realism appear to be based on too restrictive an understanding of the philosophical options. Many of his ideas about metaphors could mesh well, for example, with the brand of realism advocated by Ian Hacking. Hacking's position combines realism about unobservable entities with just the sort of pragmatic attitude towards multiple theories or models that Brown endorses. Hacking's view contrasts sharply with Brown's, though, in that it implies limits to the importance of metaphor. Microscopic entities might initially be grasped only through metaphors, but experimental manipulation provides a different sort of knowledge that is not so dependent.

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