

Conclusion

When metaphors serve scientific ends

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How Metaphors Guide, Teach and Popularize Science

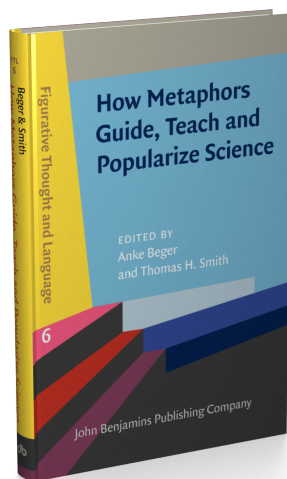
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Conclusion

When metaphors serve scientific ends

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This final chapter uses the metaphor characteristics set forth in the introductory chapter to comment on the individual studies reported here. Where the introductory chapter describes the principles of modern metaphor research that promise to improve access to science, this chapter highlights the actual application of these principles as found in the chapters of this book. When we focus on key requirements of scientific inquiry – description, explanation, and prediction – metaphor is found to be both very helpful and sometimes to pose difficulties. Such results are reviewed here, with discussions intended to benefit scientists, communicators, and metaphor scholars.

Keywords: scientific description, scientific explanation, scientific prediction, causation, groundedness, metaphor combination, abstract metaphor, generative metaphor, theory constitutive metaphor, metaphor context, propaganda metaphors

1. Scope of review

An edited volume such as this provides an opportunity to show how metaphor serves science while also contributing to metaphor scholarship. Our focus is on particular metaphor characteristics, strengths and weaknesses that may contribute to, or detract from, science and the exposition of science.

As with the introductory chapter, we address this chapter to *science communicators* (who include scientists as well as science educators, popularizers or journalists, collectively), *metaphor scholars* (experts in metaphor who study metaphor in a variety of discourses, possibly including science), and *audiences* or *audience members* (those who read about science as specialists, students, or others interested in science and its explication).

2. Characteristics of scientific metaphors

Metaphors are indispensable for the transfer of knowledge from a source domain that an audience supposedly knows well, to a target domain that is less well understood. As is the case in all discourse, scientific discourse requires this knowledge transfer and will inevitably be metaphoric. Metaphors generally function to communicate new perspectives (often with novel forms), map from a known domain to the topic at hand to frame a conceptual structure, and shift awareness and attention to activate mappings and introduce needed linguistic terms (Denroche, 2015, offers a useful review; also Chapter 1 of this volume lays out what we believe are the principal characteristics and functions of metaphor).

The chapters collected here demonstrate wide variation in these characteristics, such features as metaphor groundedness and whether metaphors appear separately or in combination with others. We note also which scientific metaphors are conventional or novel, concrete or abstract, based on bodily or cultural experience, casually or consciously chosen. But we now raise issues that are more particularly relevant to science: Do they guide scientific exploration in a generative manner or simply characterize current findings, and how central are the metaphors to scientific theory? It will be instructive to observe how these qualities and features of metaphor relate to a central scientific concern – causation.

2.1 Selection of metaphors to study: Intuitive versus systematic

In keeping with methodological trends we identified in the introduction, contributors to this volume use corpus analysis and close reading to find scientific metaphors in actual science discourse, including published scientific papers and books, videos and transcripts of lectures, and narrated audio-visual presentations. Having focused on their chosen scientific topic or target domain and assembled a corpus of material, how do scholars select those metaphors of high value? Systematic methods exist that attempt to identify and analyze all metaphor source domains in a text or corpus (such as Pragglejaz Group, 2007), and may also detect how they are arranged in, for example, hierarchies or lattice networks (such as Shutova et al., 2013; Stickles et al., 2016). While systematic, all-inclusive documentation of metaphors in scientific discourse might be useful, our contributors make no claim to survey all metaphors that might possibly contribute to understanding. They consider the context, salient parallels to the topic that may structure similes or analogies, and the metaphors that scientists who specialize in that field of study have already put to use in specialist discourse (Knudsen, 2003). In this sense the metaphors selected tend to be deliberative, are both conventional and novel, and are more intuitive than systematic.

2.2 Three purposes served by scientific metaphor: Simple description, understandable explanation and accurate prediction

In this concluding chapter we ask how these relate to three express purposes of science: description, explanation, and prediction. For the science communicator we note which kinds of metaphors stand out as instructive and worthy of close attention in these regards, and ask whether the shift in perspective they achieve is mostly beneficial for science, pedagogy, and popularization. What about metaphors that sacrifice scientific understanding in favor of other objectives such as promotion, persuasion, or argumentation? Do science writers take steps to correct misconceptions when metaphors over-simplify or even mislead?

Description comes first in most scientific writing to provide background information on the topic to be discussed, and sometimes extends throughout if study is limited to general parameters or a summary of surface details. Greater depth is provided when scientific discourse attempts to explain phenomena and predict outcomes. These latter two purposes correspond to the distinction made by some statisticians and philosophers of science having to do with what they call scientific “models” (see Bailer-Jones & Bailer-Jones, 2002; Shmueli, 2010). They compare models primarily intended for explanation versus those for prediction. Explanatory models fulfill what scientists so often insist to be essential, showing that an observed phenomenon fits a theoretical chain or network of causes and effects, how a causal process is conceived (a process that cannot be directly observed or literally described) that results in a particular outcome.

By stating these three purposes we are not asserting their preeminence in the philosophy of science, although they are certainly important, but primarily offering a framework for discussion in this chapter. The three purposes are described in more detail below with examples. This framework comes from science, not from metaphor studies, and we will see how it might challenge current metaphor theory as presented in the introductory chapter of this book.

2.2.1 *Simple description*

Scientists typically describe their topics of interest before they attempt to show the audience the inner workings. Recall the importance of target domain background knowledge in our introductory chapter. These descriptions are useful at the beginning, as when Williams-Camus (this volume)¹ tells us what apoptosis is, before exploring the metaphors used in scientific explanation of the phenomenon, or when Amin gives us background on the nature of energy so we can better

1. When an author's name is given in the text or in a citation and no date given, it refers to that author's contribution to this volume.

understand later how the Event Structure Metaphor and various blends are used to understand it. But even these simpler descriptions involve conceptual metaphors (examples: APOPTOSIS IS DEATH; ENERGY IS HEAT). Description of this sort begins an explanation, names *what* a phenomenon is, but does not give a full account or offer much insight into *how* it works, although some regularities may be signaled. So causation is omitted or barely suggested.

Scientific description alone is nevertheless essential and its delivery influences the success of scientific discourse. Ureña reviews a number of embodied orientational and primary metaphors that are mainstays in describing scientific phenomena. They are static, visual, non-linguistic metaphors widely used in diagrams, maps, and illustrations. For example, weather and ocean currents are described using visual metaphors that map bodily sensory-motor experience such as color to the scientific abstraction of temperature (RED IS HOT, BLUE IS COLD), central location to how important a feature is conceived to be (IMPORTANCE IS CENTRALITY), proximity of objects to how correlated or interactive they are (RELATEDNESS IS PROXIMITY), the shape of a line to direction of movement (MOTION/DIRECTION IS LINES/ARROWS).

The conceptual metaphors just mentioned are very concrete. Not only are they grounded in unconsciously learned, repeated bodily experience, but also everyday conversation reinforces and entrenches them, making them familiar and conventional. Each metaphor aids description and may lead to some shift in perspective, heightening expectations of certain outcomes. In that sense it may even go beyond what is intended as description and prime an audience to speculate on cause and effect. But, as is inevitable, these metaphor source domains oversimplify their target domains and, alone, each explains only minimally how the depicted elements interact.

2.2.2 *Explanatory models and metaphors*

Explanatory metaphors go beyond description and render unseen microcosmic processes as physical and mechanical, involving movement of substances or objects. They are very much conventionalized – the source domain consists of concrete entities (substances, objects) governed by the embodied experience of force mechanics, located and oriented in space – and are conceptually coherent. They seem so natural and are taken so much for granted that they are everywhere in scientific thinking and discourse as they are in any discourse: They are “used constantly and automatically, with neither effort nor awareness” (Lakoff, 1993, pp. 227–228). Of particular interest are conventional metaphor source domains of spatial relations and locations, entities or substances that move in space on paths between locations, and force dynamics that push and pull those entities – which together structure our everyday understanding of causation.

Lakoff and Johnson (1999) bring these together when they state the conceptual metaphor underlying the conventional understanding of causation as *CHANGE IS MOVEMENT* – where change is the application of physical force to an object, moving it from one location to another in space. As Brown reminds us, the notion of causation is central to science. Mechanistic models in science purport to show causation (cf. Woodward, 2017) depending entirely on these same conventional metaphors. They do this by describing a sequence of actions at a micro level, one entity acting upon another entity, much as billiard balls, set in motion, strike and move each other in succession. Add to this the Event Structure Metaphor (Lakoff & Johnson, 1999) – a pre-configured cluster of conventional, embodied metaphors that convey purpose as well as causation – and it is not surprising that science writers use this powerful, generic metaphoric structure to describe a wide range of target domains.

Scientists have been known to insist on finding such explanations – grounded in bodily, sensorimotor experience, like a picture or familiar sequence of physical events – that portrays the chain of cause and effect. Without this it seems that the abstractions alone (mathematics, for example, heavily relied upon in physics) will leave scientists feeling unsatisfied. Brown (2003, p. 85) quotes Max Planck, a leading physicist of the early twentieth century, struggling to give his theories “real physical meaning.” Embodied features easily become expository elements in scientific theories, that is, theory constitutive metaphors that offer easier-to-understand explanations that are invaluable to theory formation. Among contributions to this volume are examples of such explanatory models and metaphors.

A well-known example of an explanatory model, as summarized in this volume (Smith), depicted the unseen atom in terms of the well-known *ATOM IS SOLAR SYSTEM* metaphor. It appealed to both physicists and lay people because of its apparent clarity and specificity as to multiple elements in orbit around a central body maintained by a balance of attraction and repulsion. By so specifically depicting how elementary particles should behave, once experiments were contrived to test these hypotheses, it was concluded that electrons did not, in fact, travel in orbits around the atom’s nucleus. The metaphoric model was abandoned by scientists and new explanations sought.

Another example of an explanatory model is social field theory (also described by Smith), the central metaphor of which is *SOCIAL PROCESS IS FIELD OF FORCES*. Human social interaction is depicted in terms of the causal interaction over time of the entire network of relevant psychosocial and environmental factors ranging from micro to macrocosmic levels. The source domain *FIELD OF FORCES* was carefully chosen by theorists and seems deliberately to invoke conventional, concrete notions. The obvious Newtonian inferences, as per the sub-mappings identified by Smith, portray social factors as objects arrayed on physical terrains, impelled

to interact. Yet field theorists correct this misconception with literal language to the effect that the **FIELD OF FORCES** is an abstraction and the nature of such forces (perhaps like gravity or magnetism) is definitely not like embodied mechanical force. The theory has been very difficult to test empirically in its idealized form. With the advent of detailed computer simulations parts of the theory have been explored, metaphorically conceived as an **ADAPTIVE DYNAMICAL SYSTEM**. The theory's principal value has been to shift audience viewpoint so as to consider a much wider range of interacting, causative social factors operating at both micro and macro levels – not to predict snapshot outcomes – but more likely to give (perhaps only to hint at) an explanation of the change processes unfolding in the target domain over time.

2.2.3 *Predictive models and metaphors*

In the science of physics, at least, despite an historical preference for explanatory physical conceptualizations, what seems to have become more important is accurate prediction. Currently, if there were to be a contest between explanatory, conceptual understanding and accurate predicting, predicting would win. Physics gets its best predictions through the statistical reasoning of quantum theory and thermodynamics, even though these lack the concreteness and appeal of conventional, embodied, mechanical reasoning (Mikulecky, 2005). A modern theoretical physicist (Beretta, 2009, p. 2) decries current attitudes (compared to those of Max Planck, above) when he notes that statistical reasoning has “enjoyed such great successes that the power of its methods have deeply convinced almost the entire physical community that the conceptual problems can be safely ignored.”

While mechanical models based on conventional, embodied metaphors may fail to predict accurately, we see that they often continue to appeal. Their ubiquity indicates that science writers generally find advantage in their use. We saw this already in the case of the solar system model of atomic structure, which is a mechanistic analogy understood in terms of highly conventional, concrete metaphors. But these did not predict what later experiments revealed about the atom. So the mechanistic depiction was demoted in favor of quantum theory which did account for experimental results. Yes, prediction won and the mechanistic, explanatory model was demoted, but it still has uses and lives on in popular discourse and elementary physics texts. This is deliberate and purposeful on the part of science writers.

We saw this again in Amin's chapter where students are taught about energy. In one sense explanatory models may seem in competition with predictive ones. In another sense they work in tandem. These actual science examples of deliberate metaphor show the challenges that metaphor theory faces, and why some of the deliberate metaphor theoretical issues discussed in our introductory chapter

remain unresolved. Of particular interest are highly conventional metaphors, automatically introduced when science is explained, and later intentionally and consciously retained for expository purposes.

The Event Structure Metaphor is central to much of everyday human conceptualization. Amin reveals it depicting fictional causes for how energy works, and we see again how such a conventional, mechanical model endures even when it contradicts settled science. Recall that energy is not a “thing” or an object that behaves like billiard balls. It is a fundamental abstraction in physics, properly accounted for using entirely different principles and for which no mechanistic metaphor provides a comprehensive understanding. Nevertheless certain conventional, mechanistic metaphors are found used both by students and scientists in a pattern or sequence that narrates how energy may seem to work and prompting useful computational steps that lead to accurate predictions in certain kinds of cases. The conventional notion of the transfer of energy is metaphorically understood as a substance passed from one entity to another. Being concrete and grounded in sensory-motor experience, involving mechanical movement of substances, such metaphors end up simplifying and communicating knotty chains of scientific reasoning.

Amin shows the systematic use of multiple sub-mappings of the embodied event structure metaphors, such as to quantify energy (ENERGY STATE IS AMOUNT OF SUBSTANCE) and to think about and explain changes in the energetic state of a system, such as energy transfer and conservation (CHANGE OF ENERGETIC STATE IS MOVEMENT INTO [OR OUT OF] A CONTAINER). These attractive mechanical conceptions are recruited for use in instructional materials and found in transcripts of student problem-solving sessions.

As mentioned, these metaphors actually contradict established theory in physics. They operate unconsciously for general audiences although introduced deliberately by specialists because the inference structure helps non-specialists reason about the topic. Physicists accept scientific metaphors that are known to be misleading but offer the means for accurate prediction, are treated as necessary aids in teaching, then qualified when it is appropriate to explain current scientific understanding more fully. This would seem to fulfill the “stepping stone” or “creative falsehood” function of scientific metaphors, so long as such metaphors are actually discarded after the teaching function is complete (Steinhart, 2001, p. 7). Evidently they are not discarded, as attested by Amin’s quotations from eminent physicists.

So we see in practice the reverse of the “change in perspective” that one hopes good scientific metaphors will provide: Instead of helping students understand a difficult topic, a metaphor is used that bypasses the difficulties by *not* shifting perspective or altering customary viewpoints about complexities. These science writers must realize that misconceptions will eventually have to be addressed for

those seeking deeper understanding of the topic. When combined and sequenced with other metaphors they communicate and explain usefully; because of this they are retained. This is an example of the allure of accurate, quantitative prediction.

The allure of prediction is observed in the social sciences in a different manner. Computational data analysis models aim to accurately predict the outcomes of complex processes. Smith asserts that such models are based on metaphor; their core metaphors have become concrete and conventionalized for the scientists dependent on them, but to others they are abstract, even inscrutable. The computational models are general-purpose routines “trained by” or “fitted to” the data so as to make the most accurate predictions, that is, what an outcome is most likely to be at specified points in time. Regression analysis and neural networks are examples of data analysis techniques useful in refining predictive models. Conceptually this approach omits theories or representations of real-world dynamics or processes involved in producing outputs, and substitutes data structures and the processes of computation. They are optimized for specific applications. Consequently they are of less value in development of scientific theories concerning the topic being studied. Another example is the mathematical model of the atom that probabilistically predicts locations of atomic particles where the solar system model fails to do so (Smith); it substitutes (in this case) mathematical structure for physical structure or experiential gestalt. The predictions are accurate in terms of the laws of quantum theory. But the metaphor source domains are not what conceptual metaphor scholars might expect.

Audiences fully familiar with the mathematics may metaphorically use the math in a predictive model as an abstract source domain for the physics target domain; as discussed in the first chapter, this reverses the more common relationship found with conceptual metaphors where the source domain is concrete and the target abstract. Smith describes another such example, the *DATASET* metaphor, used by social scientists who focus on violent macro aspects of law enforcement, relying on the metaphoric structure of their statistical reasoning and largely ignoring the social dynamics that may cause the results they find. In order to grasp why black people are more often shot by police than white people in the U.S., the audience must join the social scientists as they map structure from multivariate regression equations to the target domain of social process. Such mapping may seem forced, but note that the social scientists, having mastered their computational tools at a concrete level, can explain in detail how the equations have traceable correspondences to their extensive and carefully coded datasets. The dataset and regression statistics become a concrete source domain for these scientists and this may satisfy a desire for “real physical meaning” at an embodied level. Smith indicated how such computational source domains influence scientists’ to adjust their computations, such as adding new terms to equations. This substitutes for the

generative effect or new ideas expected of scientific metaphors. If this satisfies the social scientists, the source domain remains abstract for the non-specialist audience who continue to wonder about the social processes that result in violence.

When the source domain is as, or even more, abstract than the target domain, “this makes these metaphors somewhat marginal instances of metaphor” or not even like metaphors at all (Kövecses, 2005, pp. 266); while the quantitative predictions are expressed by the mathematics, the scientific process seems unexplained – cause and effect are not conceptualized – and whether they adequately guide scientific exploration remains an open question.

2.3 Social models and metaphors: A level of scientific analysis where physically embodied metaphors may not work

In biology, to the extent that explanations reduce to mechanistic conceptions of classical physics and chemistry (such as individual cell nourishment, elimination, energy production, cell division), these unseen microcosmic biological processes have historically been understood metaphorically and grounded in OBJECT, MOVEMENT, SUBSTANCE, and CONTAINER (Liu, 2016).

But much of biology cannot meaningfully be reduced to underlying principles of physics and chemistry. This is because of the long chains of unseen micro-events that are untraceable or too intricate or overwhelmingly tedious to summarize, thus relatively useless as explanation or a depiction of causality. At the microcosmic level individual cells are containers of chemically generated protoplasmic substance that reproduce through physical division. But, as Brown points out, cells combine to form differentiated organs with distinct functions at a macro level. So more macro, abstract social source domains might best be used to summarize and characterize these biological functions.

Social metaphors need not be vague if they are understood in terms of actual, concrete experience, as discussed in the introductory chapter to this volume. For example, GROUPTHINK might be vaguely recognized by most people, but relatively few recall having experienced it, much less formed a gestalt. So, for them, this source domain would most likely explain little and predict nothing. Such variation should prompt science writers, if they are to use social metaphors, to select those with source domains that are very common and widely experienced. Otherwise, as seen below, audiences must be carefully instructed on details of a particular source domain.

Social source domains offer a macroscopic view and, in general, their use makes quantitative predictions as required by physicists unlikely. But their explanatory power may point in new directions and can guide scientists to look

for certain kinds of evidence as they study their fields of interest; creative, novel, alternative conceptual interpretation becomes more likely (Kövecses, 2005).

Micro-organisms are so small and primitive that they, as individuals, might survive, but not thrive. However, in very large groups they can dominate. Brown describes a target domain where certain micro-organisms reproduce benignly and then, only when there are enough of them, release toxicity and overwhelm the host. Brown offers another target domain: Several different strains of micro-organisms together form a biological film, each strain secreting a constituent substance sequentially in a complex series of steps, forming a hard surface that protects them. How this happens is not directly observable so must be inferred metaphorically from, in this case, the known behavior of human social groups that perform complex tasks. Brown's discussion shows biologists' creative choice of a framework based on social metaphors rather than biological mechanisms reduced to chemistry and physics. Directly mapping the social source domain to a biological target domain appropriates social terms for use in biology.

Social metaphors, depicting a higher macrocosmic level become the basis for metaphoric source domains such as COLONIES, COLONIZERS and QUORUM SENSING. Single-cell organisms are then seen to form groups, communicate through signalling and sensing, and ultimately cooperate to their mutual benefit.

Note that such metaphor source domains are not necessarily concrete, the language used is abstract and fails to evoke a reliable experiential gestalt. In the absence of background knowledge that makes source domains properly understood or even familiar, misconception can occur (Cameron, 2003). This is the case with QUORUM, a source domain vague to some, which requires the science writer painstakingly to describe what a human quorum is, along with its communicative properties and purpose in deciding action. All this must be laid out before the audience might come to appreciate the novel perspective that a deliberative human grouping as source domain brings to the target of collective behavior of micro-organisms. As Brown describes, this and other social metaphors have pedagogical value as well as their own inference structure which, in turn, has helped scientists form hypotheses as to what to look for next.

While making explanatory sense these social metaphors do not help quantitative prediction. But they do invoke sub-mappings of JOURNEY, COMMUNICATION, THE COMMON-GOOD, and COOPERATION, suggesting what to look for at a macro level (such as toxicity-sensing capability in each micro-organism). It is from these sub-mappings that the audience might infer a teleology that organizes millions of micro-organisms as an intercommunicating, unified whole, even though such inferences are mistaken and epistemologically confusing. Nevertheless, when at first novel, they succeeded in generating hypotheses, prompting biologists to look for the necessary signaling processes. The hypotheses were productive, scientists

found that the signaling processes did indeed exist, and the social metaphor became theory constitutive. But in time the status of such metaphors may change.

In fact, such social metaphors in biology have proven so useful, as Brown reports, that their linguistic expressions have become commonplace in biology. “Quorum sensing” once having entered the biology lexicon, established itself in the specialists’ vocabulary as a technical term and convenient label,² communicating precisely the specific meaning already assigned. When this happens we have seen that there is danger of metaphors becoming closed (Knudsen, 2003) so that source domain features are no longer mapped to the target (Semino, 2008), in which case they tend to be taken literally; they no longer promote any new perspective or guide scientific exploration in a generative manner. Causation could be interpreted anthropocentrically when it should be “microbe-centric”. Will this undercut explanatory usefulness or lead to audience confusion despite, as Brown points out, their popularity stimulating an abundant flow of new experimental evidence?

So far, metaphors have been presented individually, but it is clear that a metaphor seldom if ever operates alone. There are inevitably combinations of metaphors or other figurative elements, such as background metaphors or cultural narratives, that frame the discourse.

2.4 Groupings of metaphors

Often, not one, but multiple metaphor source domains are needed to cover all important facets of an unfamiliar scientific target domain. But how might each relate not only to the target domain, but to each other? These are issues studied by metaphor scholars but probably seldom considered in any detail by science writers, even though metaphor combinations are key. A variety of forms are discussed in our introduction, and specific examples appear in chapters of this book.

Williams-Camus investigates several metaphors used singly and in combination by scientists and science writers to describe apoptosis, the natural occurrence of cell death. Note that it was necessary first to describe the notion of cell death (the target domain) to readers before giving the linguistic evidence of metaphor source domains that potentially explain how apoptosis works. As reviewed in our introductory chapter, this situation is common in scientific discourse generally because, except for specialists, the intended audience may be unfamiliar with the scientific topic being discussed. The science communicator must somehow assess

2. The number of biological links found on internet search engines after entering “quorum+biology” as the search term is approximately 500,000; note that definitions now given in the results of such searches are highly technical, have only direct referents and no figurative meaning, as Knudsen (2003) would have predicted.

the general frame, that is, find out approximately what the audience already knows and doesn't know, perhaps also what the audience knows it doesn't yet know, making it especially ready to learn. Using the language of mental spaces (Sweetser & Fauconnier, 1996), target domain background knowledge defines a mental space to which source domain structure can be transferred.

In Williams-Camus' case APOPTOSIS IS CELL SUICIDE would be considered novel in the context of biology. The very conventional DEATH metaphor is not embodied or physically experienced by the living, but a culturally disseminated notion, and mostly in terms of its association with (usually negative) emotions or images in social experience. CELL SUICIDE is widely used even by scientists discussing apoptosis and seems successful as a term that attracts attention and promotes interest in the subject. But not only does this metaphor fail to explain why or how, or to predict when, a cell will naturally die, it also mistakenly implies a self-imposed, shameful, hurtful, unnatural passing. So, while this metaphor is used in ostensibly scientific discourse, is it scientific? Scientific investigation shows that apoptosis is a necessary process that, should it fail to happen, leads to uncontrolled cell growth and cancer. Fortunately APOPTOSIS IS CELL SUICIDE is not used alone.

One of the other metaphors often used at the same time does more than simply complement or supplant the SUICIDE metaphor. APOPTOSIS IS PROGRAMMED CELL DEATH, avoids the idea that cells somehow may choose to die or are agents in their own early demise, and instead that death at the right time is built-in and appropriate. Furthermore it has the generative effect of prompting scientists to look for (and make very useful discoveries about) the nature of the programming and how it is controlled. When these metaphors are used together in the same writing the result could be interpreted as a conceptual integration or blending (Fauconnier & Turner, 2002; Kövecses, 2005) of concept spaces coming from each domain; is this what the audience ultimately understands? Their juxtaposition projects drama to the target domain (voluntarily dying so young!) while immediately modulating misinformation (death fits in a larger and generally healthy pattern).

Note that these two metaphors have the same target domain; their conceptually fragmented source domains both deal with death, but they are neither hierarchically organized nor conceptually aligned. Williams-Camus considers the contribution to understanding that each metaphor might make individually, reviewing the mappings found in corpora in two languages, and how they compare for scientific and science education purposes. Alternatively we may speculate that the aptness/inaptness of various mappings, while misleading to some, propagandistic or fictional, result in a dissonance that may actually highlight key aspects that scientists face in understanding what remains a mystifying scientific phenomenon. For example, blending or integration of source elements from PROGRAMMED with those of SUICIDE suggests the notion of a predestined flip-flop

from wanting to live to wanting to die; or that death is not a matter of some failure in the present, but occurs at a pre-specified time regardless of concurrent circumstances. This conceptual integration seems to have been operating for scientists hoping to reverse cancerous cell reproduction by searching for ways to promote apoptosis: They looked for what caused, or failed to cause, the pre-specified time for tumorous cells to die.

Such metaphor integrations may be only temporary and dependent on context; they are ephemeral in the sense that they leave an impression more than make a statement. So they are not unlike multi-modal metaphors in some advertising and cinema that appear incongruent at first but may, after a short interval, blend in unforeseen ways (Forceville, 2016). While dissonant combinations of scientific metaphors might be understood and consciously intended by science writers to produce such effects, this doesn't appear to be the case for those writing about apoptosis. If science writers were metaphor savvy, and took some care in metaphor selection, wouldn't we expect, not dissonance, but metaphors that are conceptually aligned?

For conceptually aligned scientific metaphors, consider Ureña's account of the multi-modal metaphors (visual, auditory, as well as verbal), presented via modern video technology, that are used to teach marine biology students about certain under-sea creatures. The impact of this multi-media scientific discourse dramatizing natural phenomena is maximized through cinematic refinements of timing, sound volume, and content selection combined in scenes of gritty, live action. Its impressive strengths, as well as epistemological weaknesses, become evident.

In this example the very conventional source domains of *LOUD SOUNDS*, *SOCIAL CONFLICT* and *WAR* are taken from the instantly recognized and potent source domain of human society and used to explain the nature of these marine creatures and to predict what they will do next. This example, along with those of microbe quorums and cell death, above, are eminently capable of instantly shifting audience's perspective. But they imply notions of anthropocentric subjectivity and human group dynamics. Correspondingly, sub-mappings such as *PURPOSE*, *CHOICE*, *KINSHIP* and *STATUS* inevitably structure these metaphors and can create expectations in the audience. To what extent do these map true and useful correspondences versus fictive and misleading ones? Are we to understand that sea creatures intend to frighten their adversaries, that they choose which ones to fight based on species differences? Does the understanding we gain from these metaphors suggest how to predict future behavior or that of similar species?

Nor is it clear, even though the manner of exposition rivets attention on the source domain, that the communicators who produced these materials have deliberately chosen the metaphors for their scientific pedagogical value. A deliberative marine biologist wouldn't wish that the causes of animal behavior be understood

as the emotional causes of human behavior, or to predict their actions always to consist of fighting, dismemberment and death. Such interpretations are extreme simplifications, they risk relegating scientific conceptual metaphors to the status of ornaments and, in addition to how they may mislead the audience, have no obvious value in guiding scientific exploration.

We might expect that the metaphor-savvy science communicator will anticipate how particular conceptual sub-mappings interact and then (hopefully) will compensate for misleading blends. For science communicators this suggests that these videos might best not be left to stand alone, but that some kind of integration with other, perhaps linguistic, metaphors that accompany the auditory and visual ones, should be contrived. In this case linguistic metaphors were included also, namely, *WEAPONS* and *WAR*, but they seem only to align with the non-linguistic ones, amplifying them. It would certainly be desirable to offer a broader interpretive framework, as occurs with some of Ureña's other multi-modal examples. Science writers who are trying to attract the attention of bored students may ignore such issues, but those intent on clarity, accuracy and causality cannot.

2.5 Metaphors for argument and propaganda

Here is an example of the use of multiple micro-level metaphors to characterize a macro state of affairs. It is instructive both because of its success as scientific metaphor and what many would say is misuse of metaphor. Von Wülfigen tells the story of a very complex biological target domain, human reproduction, in the context of an unusual shift in public opinion from a restrictive to a more favorable view of human reproduction technology. Conventional metaphors from both embodied and cultural domains are shown to play a key role, as is the manner in which they are deployed and related, one to another, to heighten their saliency and help the lay audience comprehend target domain complexity.

Fruit cultivation is used in the attempt to convey that technological interventions in human reproduction are clear, simple, natural and beneficial – *HUMAN REPRODUCTION TECHNOLOGY IS CULTIVATION OF FRUIT*. Botanic metaphors are conventional, concrete and a matter of daily experience at least for some audiences today, if less so now than in the past. Note how the metaphors make human reproduction – a highly complex life process – seem distinctly mechanical. It could be argued that the target domain of the metaphor is not so much the technological process of ameliorating human reproduction as it is the steps to advance it in a prescribed way. Considered in this way, the fruit cultivation metaphor describes mechanical onward motion to complete a task: choose the bedding plant (embryo, examine and perhaps edit the DNA), implant it in garden (uterus), care for it and then harvest – radically simplifying and concretizing a complex process.

The CULTIVATION OF FRUIT metaphor is combined with other conceptual metaphors that also are conventional and easy to understand, mapped to the same target domain. They exhibit complementary interrelationships among themselves that provide an ideational context for the complex topic, and then we see them neatly situated together within a dominant cultural narrative. This intertwining of metaphors leverages their power to advance a deliberate propaganda initiative: Reproductive technology is advantageously framed as timely and important, making its exploitation seem like common sense. Note how the conventional botany metaphor explaining human reproduction (metaphorically understood as FRUIT), combines with offspring characteristics being determined by DNA (TEXT) which, left to chance, involve danger and risk (ROLLING DICE), then overcoming the risks through scientific management (OBJECT MANIPULATION) of the human reproductive process. This is a JOURNEY, involving VISION of the future, bound to give superior results. The latter three source domains are grounded in embodied experience, operate unconsciously, and require no preliminary description. The first four are learned from conventional cultural experience but their value as source domains is increased by offering background knowledge – factual statements about the reproduction process.

Persuasion in this case is enhanced by a worldview that need not be stated explicitly, is not found in the corpus texts, because it is pervasive in the culture (a kind of background or necessary metaphor – key to a particular understanding even without restatement or verification). This worldview dates from the Age of Discovery and the beginnings of the Scientific Revolution and is still affirmed today – the utopian cultural narrative promulgated by influential Renaissance figures such as Francis Bacon who elevated human choice and ingenuity in determining destiny. It encourages us all to see ourselves capable of escaping nature's arbitrariness, deciding what we want, and taking steps to get it. The result of this layered formulation shows conventional metaphors found in contemporary texts dealing with this target domain, interpreted within the context of historical and cultural allegory, yielding an effective argument.

The metaphor combination might be regarded as much more compelling than the sum of the individual metaphors. Discussing them in this way suggests that, if purposefully deployed by science writers, they can successfully shift public opinion. The metaphors do not benefit scientific theorizing and are not theory-constitutive. Even minimally informed lay people know that babies are not like plants, DNA is not text, and even the best technology cannot assure risk-free wish fulfillment. The contrasts between metaphor use in science and metaphor use in persuasion are thus highlighted. While they give a macro view of a complex topic, they do not properly explain human reproduction nor fully describe technological interventions, so they lack both predictive and explanatory power. They may

instead breed troublesome misunderstanding. Whether all audiences realize they are receiving a promotional message is unclear. Should not science writers provide a warning in such cases and, at least, footnote possible misinterpretations?

2.6 Macro metaphors and argumentation

What might be better able to give a macro view of a complex scientific topic, be theory-constitutive and also enable scientific explanation and prediction? To explain complexity at the macro level – to try to take in the whole of a complex phenomenon – an inherently more complex source domain may be needed. A source domain useful for complex topics will itself be complex, abstract, and may not initially be well understood by the audience. An oft-used such source domain is the machine and today's premier machine is the computer – available as a highly structured metaphor with many possible interrelated sub-mappings.

As another example where we learn from less-than-optimum use of scientific metaphor, Beger offers a revealing history of a theory-constitutive metaphor in neuroscience. It is the now very common COMPUTER IS BRAIN metaphor, in particular, A BRAIN'S MIND IS A COMPUTER PROGRAM. A matter of lively debate originating fifty years ago, the COMPUTER IS BRAIN metaphor is now entrenched and often believed literally true among those who may know relatively little about either brains or computers. We learn of deliberate metaphors, presented as elaborate philosophical analogies, constructed for argumentative purposes but scarcely explaining the subject matter. Used in three discourses with the same target, it is a unique opportunity to examine deliberate metaphor, communications function, and metaphor recontextualization.

A conceptual metaphor for which the source domain is vague or ill-defined, over-simplified, or idealized, can generate varying interpretations that become susceptible to disputation, and thereby lose informational value. In this case background knowledge of the COMPUTER PROGRAM source domain ought to be, but probably isn't, assured.

For most people, understanding the brain metaphorically as a computer is not grounded in bodily experience or universal gestalts. The source domain, COMPUTER PROGRAM, is certainly very abstract in that there are so many variations among computer programs, their structure and features. The ubiquity of computer devices today does not offer experience with the inner workings of computers but with their interfaces that don't actually exist inside the computer (Laurel & Mountford, 1990).³ How, exactly, is this source domain to map onto what "a brain's

3. Interfaces themselves are deliberate metaphors contrived to invoke familiar real-world schema (such as the "desk-top").

mind” consists of? Whatever blend of source and target that occurs can be idiosyncratic and relatively useless as scientific explanation if it omits an understanding of the dynamics or processes involved. Of course, at the very least, we identify a rudimentary metaphor of a mechanical, industrial machine that accepts inputs and produces outputs. Taking that as literal truth may be likely to occur.

Because this source domain is not concretely experienced or culturally learned (except perhaps for a small audience) the author who initiated the debate gave a description of the source domain, carefully contrived and articulated as a lengthy hypothetical task. Still it may not have been clear in readers’ minds. Whether or not *BRAIN’S MIND IS A COMPUTER PROGRAM* is accurate as analogy was debated over decades and Beger shows how advocates have taken it out of its original context and modified it for argumentative purposes as the disputation continues, and later recontextualized it for educational use in a different discourse event. Nerlich (2007) notes that different scientific metaphor source domains, but with the same target domain, will vary considerably and that a given one will gradually shift depending on how it is used and reported. This seems to be what Beger has found to have occurred. Kövecses (2015, p. 31) describes intertextual reuse of metaphors and characterizes such shifts as “usurpations of metaphor against our original intentions ... turning [our] metaphor against us in a debate over contentious issues.”⁴

This is a paramount example of metaphor in science because it shows that even contrived scientific metaphor, constructed hypothetically and inaccurately mapped, has explanatory power when the audience is induced to try to follow the mappings and to understand. This metaphor has bred misconceptions but evidently raised issues well enough for scholars to retain it for decades, use its distinctions and argue its aptness as analogy. We may deplore certain authors’ opportunism to score points by repurposing their competitors’ metaphors, stretching and elaborating the source domain to further their academic argument. Still, having worked through the arguments, many of which are based on distortions, and noting the array of issues it raises for metaphor studies, the reader will be much better informed about the topic under discussion, if still not understanding

4. What would be required of this metaphor to generate ideas about brain function? Only for those steeped in microprocessor operation, transfer and storage of signals, and the reusable functions and subroutines that transform inputs into outputs, might this metaphor be useful in describing, explaining or exploring the brain; for example, simultaneous activation of multiple parts of brain metaphorically understood as parallel processing in different components of a computer, generation of emotion understood as signal transmission and information integration, sub-parts of human behavior metaphorically understood as computer subroutines and functions (Marcus, Marblestone & Dean, 2014).

how the mind works in any comprehensive way nor being able to better predict what it will do.

3. Some conclusions

Briefly, here are some of the things covered here that may (1) help a range of science communicators engaging in science, pedagogy, and popularization to better use metaphor in making science more accessible, and (2) help scholars to advance the study of metaphor.

With such a wide variety of ways that science has been presented, almost any of them offer an opportunity to study metaphor. Contributors to this volume analyze conventional science writing, science infotainment, scientific charts and diagrams, science-related propaganda, arguments about science, and each of them offer their own special window into the nature of metaphor. The assortment of scientific disciplines treated here demonstrates, should anyone doubt it, that metaphor is important in all of these and more.

At an earlier time scientists and philosophers insisted that metaphor had no place in scientific discourse, nor was it legitimately to be found, because metaphor was fanciful, ornamental, and might be entertaining but could not tell the truth (Williams Camus, 2015, reviews this p. 247). With Conceptual Metaphor Theory came a recognition of the importance of metaphor in expressing scientific concepts. And corpus analysis of the actual scientific writing of specialists, teachers and popularizers showed how widely metaphor actually occurs and how advantageous it is. With the use of metaphor in science having been legitimized, attention to the details of actual scientific discourse also documented how often metaphor is exploited for the purposes of promotion, propaganda, entertainment, and argument, often at the expense of scientific “truth-telling” and accuracy. Metaphor scholars contributing to this volume attest to this, as commented on above.

Would it be radical to insist that science writing put accuracy first, and that exceptions to this dictum be accompanied by cautions, warnings, corrections, or alternative interpretations? Metaphors used in science writing would then be judged according to certain standards that might not apply to metaphor use in other fields. We have argued here that metaphor should, as top priorities, serve scientific description, explanation, and prediction. Some may prefer to prioritize other goals such as exploration, empiricism, or classic forms of the scientific method. Any such set of priorities will imply in turn their own list of standards that metaphor should strive for if it is to be helpful in scientific knowledge transfer.

In what ways can metaphor scholars particularly help science communicators to make science more accessible? Might science writers be expected, as suggested by

some contributors, to become more metaphor-savvy, conscious of how metaphors work and skilled in their use? Metaphor scholarship as presented here documents the ease with which conventional, concrete, embodied metaphors convey useful information, how combinations of metaphors, including visual and auditory ones, enhance understanding, the pitfalls of abstract source domains, and the ways that misconstruals might be avoided or corrected. Social and cultural *gestalts* are a rich source of structure that metaphor scholars might help science writers deploy, again with precautions to avoid audience misunderstandings. Science writers might use metaphor combinations more openly, that is, remind their audience that metaphors are, in fact, deployed and show how they interact. The difficulties and advantages when metaphoric vocabulary enters a scientific lexicon is another matter illustrated here that science writers should understand. Because so much metaphor is used unconsciously – and effectively – would being consciously savvy actually be better?

When used in science discourse, how effective are metaphors in transferring knowledge? Most analyses make this evaluation based on the structure of metaphors found present, the inferences the metaphors might make possible regarding a particular target domain, the terminology introduced by metaphors and adopted by scientists, or how long the metaphors have been retained and continue to appear in a particular discourse. In this volume we find that metaphors in popular media are said to change public opinion (von Wülffingen), although there was no comparison group with which to judge the effectiveness of metaphors in the context of other factors; in another chapter there are careful assessments of how key metaphors in science education are relied upon in instructional texts, transcribed problem-solving discussions, and in the seminal writings of leaders in the field (Amin). Although not referred to here, there is literature relevant to deliberate metaphor that experimentally examines analogical learning and problem solving (such as Gentner et al., 2003). So the tools exist to evaluate metaphor effectiveness in science. The results of such evaluations could be key to improving scientific discourse and invaluable to metaphor scholarship.

But what about helping audiences more directly? Can metaphor scholars help audience members learn better from the scientific metaphors they encounter? Much has been said about how science communicators use metaphor and how they might use it better. But such discussions seem to assume that, while the communicator can adjust metaphors to meet an audience's level of knowledge or their possession of different kinds of learned *gestalts*, they always seem to assume that audience members are passive recipients unable to actively notice and reflect on the metaphors fed to them. They might learn close reading techniques to become aware of when metaphors are being used and the best ways to interpret them separately or in combination, the spectrum of inferences conveyed, which

are intended, not intended but novel and useful, intended or not intended but misleading, and how they relate to literal parts of the discourse.

Metaphor scholars can learn much from the studies found here and the questions they generate. Discourse among specialists, as well as that directed to the public, benefit from grounded metaphors that are salient, vivid, concrete, and memorable. Metaphor scholars might look to see if, in general, metaphors used for description and explanation are mostly concrete and embodied as found in studies reported here, and if those used to aid prediction are more abstract and require a higher level of audience background (technical, mathematical) knowledge. How widespread are the temporary, creative fictions that use concrete embodied metaphors as stepping stones to more complete understanding? Are their fictional elements usually revealed in due course, or is the audience left to sort out distortions on its own?

The various ways depicted in scholarly writings that metaphors work in combination, as briefly reviewed in the introductory chapter, were often difficult to identify in the studies presented here. Since different kinds of combinations so clearly influence audience understanding, more metaphor scholarship on this subject is needed. When social source domains are used, does personification and anthropomorphism, besides creating interest, lead to permanent misunderstanding or even magical thinking?

Do scientists, when using metaphors judged to be closed and reduced to literal, technical meaning only, find them no longer inspiring of new hypotheses? Or, even though having become technical terms, do they still possess generative qualities that may pose new scientific hypotheses? Existing literature (Knudsen, 2003) indicates that they are still useful for changing viewpoints of non-specialists. Reported here is the tendency on the part of journalists to use scientists' metaphors, occasionally extending them to include more colloquial linguistic variants. This raises questions about the real nature of a "closed" metaphor and whether extensions or linguistic variations may restore their metaphoricity.

When metaphors are used for special interest promotion, or for debate and argument, does this help with scientific understanding, or merely stimulate audience attention. Does the inducement to follow tortuous inferences coming from promotional or argumentative metaphor somehow teach about a target domain accurately or usefully, despite the inferences being partially or wholly fictive? Scientists and communicators may be well advised to avoid application of metaphor for propaganda and argument. But we saw in accounts given here that such persuasion campaigns or academic debates, when in progress and having engaged the audience, seemed to serve science in certain ways. If explored by metaphor scholars, this, like so many other issues raised in this volume about science, would greatly expand our general understanding of metaphor.

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