Figurative Thought and Language 6

CHAPTER 1

Introduction

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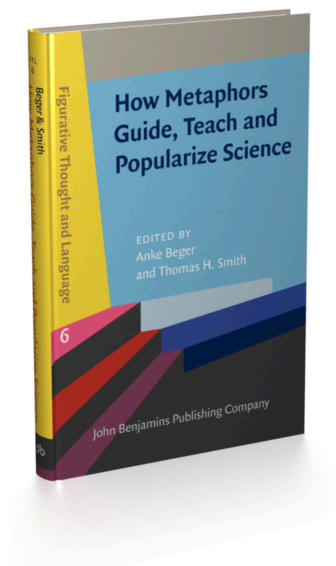

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CHAPTER 1

Introduction

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In this introduction, we start by providing an overview of how metaphor makes science accessible (§ 1). The first part describes the intended readership of this book and introduces them to studies of metaphor in science. We then provide the theoretical foundation for the study of metaphor in science that all of the contributions in this volume are based on: Conceptual Metaphor Theory (§ 2). The third part (§ 3) introduces the three interrelated functions or levels of metaphor that are vital for making science accessible: language, thought, and communication. An overview of contributions to this volume concludes this chapter (§ 4).

1. How metaphor makes science accessible

The motivation for this edited volume on metaphor as a means to make science more accessible is a desire to discuss the essential functions of metaphor in conducting, teaching, and popularization of science. We want these fundamental functions to be concentrated within a single volume – a book that is itself accessible to scientists, science teachers, and science popularizers – and to lead to a better understanding of science, science pedagogy and, hopefully, better science.

1.1 Accessible to whom? Intended readership of this book

Whereas readers of texts written by scientists or popularizers of science are primarily interested in the scientific topic being elucidated, readers of this volume will attend not only to each scientific topic but also to how the metaphors work to explain them – to make the scientific topic accessible. This book is of interest to various groups of people who work in, study, or are interested in science and science education or popularization. However, we organize these groups into three categories according to common interests or roles within the fields of science and metaphor.

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The first category of intended readership includes scientists as well as science educators, popularizers or journalists, each operating within their own scientific, pedagogical and popularized discourse communities. While these professions, as well as their general audiences, differ in their detailed roles, they have in common that they communicate science to others. Whether their audience consists of colleagues, students, or the interested public, members of this category should find this book helpful in actually *enhancing* science accessibility. In correspondence with this shared interest, scientists as well as science educators, popularizers or journalists are collectively referred to here as *science communicators*.

The second category of readers are *metaphor scholars*. They are experts in metaphor rather than science, but study metaphor in a variety of discourses, possibly including science. For metaphor scholars, this volume is valuable because it provides them with insights of forms and functions of metaphor in yet another very important and broad discourse domain.

Finally, intended readers include those who read about science as specialists, students, or others interested in science and its explication. They share an interest in having science made more accessible for them. These groups of readers are referred to here as *audiences* or *audience members*.

1.2 An overview of the study of metaphor in science

The value of metaphor in science and science pedagogy was recognized as early as in Ortony's 1979 collection of chapters on metaphor and thought that featured an entire section of contributions on this topic. Since then metaphor research has developed considerably: negotiation of what constitutes a metaphor, improved methods, and wider fields of application. Despite these developments there have been few promising studies published or reported at recent conferences that, although beneficial to metaphor scholars, effectively addressed our other groups of intended readership.

Over the last 15–20 years, publications on metaphor in science and science popularization have been rather scattered, which makes it difficult to quickly establish an overview of the role of metaphor in science. Furthermore, it is often the case that only one of the three aspects of metaphor in science, that is, conduct of science, teaching of science, popularization of science, is addressed. Thus, prior publications often lack the synthesizing effect that is needed, as these three aspects of science are deeply intertwined. Most monographs and edited volumes focus on metaphor in science conduct, neglecting science pedagogy and popularization (e.g., Brown, 2003; Ervas, Gola & Rossi, 2017; Hallyn, 2000; Nerlich, Elliott

& Larson, 2009).[1] The few books that include science popularization or science pedagogy either do not take into account new methodological developments in metaphor analysis (e.g., Giles 2008) or are not exclusively devoted to science discourses, reporting on specialist discourse in general (e.g., Herrmann & Sardinha, 2015, which, interestingly, besides science and other technical subjects, includes metaphor in football radio commentary).

Considering the various studies in these works, some general conclusions can be drawn at this point.

- First, the degree of conscious or intentional use of metaphor can be seen to vary widely. Some scientists are meticulous in their use of analogical models, such as the nineteenth century physicist James Maxwell, who is said to have helped with visualization of lines of magnetic force by explicitly stating the analogy of fluids in motion (Miller, 2000, p. 149). Some science communicators focus intently on the rhetorical impact of metaphors; THE HEART IS A PUMP is widely employed to frame what the heart does hydraulically with blood pressured through pipes, emphasizing prominent features of the circulatory system without contradicting common knowledge of the heart as an exquisite and complex organ. Contrast this with how others, sadly, "are oblivious to the pervasive workings of conceptual metaphor in shaping our conceptual systems […] constraining inferences in ordinary thinking, scientific research, and philosophical theorizing" (Johnson, 2007, p. 200). Among many possible examples is Darwin's use of EVOLUTIONARY CHANGE IS JOURNEY and GENETIC MODIFICATION IS CHANGE IN PHYSICAL SUBSTANCE, further represented in terms of family and a genealogical tree without any recognition that the Theory of Evolution recruited mappings from these conceptual metaphors (Drogosz, 2016).
- Second, metaphors are essential to scientists themselves and strongly influence science communication. Just to take one instance, scientists talk metaphorically of quantities or variables as points on a physical line, a line that is continuous and without gaps (Núñez, 2000). So entrenched is this example of metaphor that, without it, scientific measurements could hardly be communicated at all.
- Third, including the above and much else, there is a general interest in metaphor in science that continues unabated, particularly in the most recent works (e.g., Ervas, Gola & Rossi, 2017; Herrmann & Sardinha, 2015). However, as Cameron observes in the preface of Hermann and Sardinha's (2015) volume, it is vital to a deeper exploration of metaphor in scientific discourse to take

1. While the edited volume by Ervas, Gola, and Rossi (2017) does feature a section with articles on metaphor in education, the contributions are not necessarily concerned with the use of metaphors when teaching scientific content.

into account an important shift of metaphor studies, namely, to a more discourse-based point of departure (cf. Cameron, 2015, pp. xi–xii). In our view, more carefully documented analyses of metaphors as they are actually used in science texts, recordings, or videos is key in making science more accessible.

2. Theoretical foundations for the study of metaphor in science

Metaphor studies have shifted in several ways over the past decades, both in terms of theories about metaphor and the methodological approaches taken. These changes are important to understand for those concerned about metaphor in science. This overview is intended not only for metaphor scholars, but also for anyone hoping to gain greater access to science and to improve science presentation.

2.1 Main tenets of Conceptual Metaphor Theory

The focus here on Conceptual Metaphor Theory (CMT, Lakoff & Johnson, 1980) as a theoretical foundation for studying metaphor has two justifications: One, despite alternative theories of metaphor (for wide-ranging reviews see Gibbs, 2008, and Holyoak & Stamenković, 2018), our reading of the current literature puts CMT as still the leading paradigm for metaphor studies in Cognitive Linguistics and Applied Linguistics. The second reason is a reflection of the first and is that most chapters in this volume heavily draw on CMT as a theoretical basis. So we start this introductory chapter by reviewing the main assumptions underlying CMT (2.1.1), before we address critical aspects (2.1.2).

2.1.1 *Conceptual Metaphor Theory: Main tenets and assumptions*

In Conceptual Metaphor Theory, metaphor is primarily seen as a cognitive phenomenon, as a mapping between two conceptual domains (Lakoff & Johnson, 1980; Lakoff, 1993). The basic and most important function of metaphor is that it makes an abstract or less familiar domain (e.g., ELECTRICITY) accessible through a mapping from a concrete or more familiar domain (e.g., FLUID), whereby a mapping is considered a set of correspondences (e.g., 'the flowing of fluids' corresponds to 'electric current' and 'obstacles in the flow of water' correspond to 'electrical impedance'). Lakoff and Johnson (1980) argue that our ordinary thinking is largely structured by such metaphorical mappings. The notion of metaphor as a phenomenon of thought rather than merely a feature of language is quite powerful in that it presumes that we need metaphor to reason about all kinds of abstract concepts. Since science is predominantly concerned with examining abstract and/

or unfamiliar concepts, metaphor is, according to CMT, an indispensable tool in making science accessible.

While metaphor is seen as primarily a cognitive element, Lakoff and Johnson (1980, p. 7) argue that we can study metaphor in thought (conceptual metaphors) by examining language. According to CMT, we find patterns of metaphor in ordinary language that are systematic in that numerous metaphorical expressions come from one lexical field (e.g., "fluids") but are used to metaphorically talk about a different topic (e.g., "electricity"). This systematicity in metaphor use in everyday language is seen as a surface manifestation of conceptual mappings (Lakoff, 1993, p. 244).[2] Thus, within the CMT paradigm, linguists and other metaphor scholars have been analyzing metaphors in language to uncover conceptual structures for the past four decades.

Another aspect of CMT which is important for science and science communication is the notion of partial mappings. While a conceptual metaphor like ELECTRICITY IS A FLUID maps aspects from the source domain FLUID to the target domain ELECTRICITY to allow us to understand electricity in terms of fluids, the mapping between the two domains is only partial. That is, only certain aspects in fact correspond between fluids and electricity, and only those can be used to reason about electricity in terms of fluids. It is important for science communicators to be aware of the actual or useful correspondences as well as the limitations of the mapping to avoid risking that audience members make wrong inferences about the nature of the target domain (topic). If audience members transfer parts of the metaphor's source domain (e.g., FLUID) to its target domain (e.g., ELECTRICITY) that are *not* part of the useful mapping (e.g., fluid viscosity or thickness maps inaccurately to electrical impedance), they are likely to form a faulty concept of the topic at hand.

2.1.2 *Criticism of CMT and alternative approaches*

Although Lakoff and Johnson (1980) are chiefly interested in metaphor as a cognitive phenomenon, their early works do not include any support from psychological or psycholinguistic experiments to test their hypotheses about the cognitive structures or the psychological reality of metaphors. Instead, the reasoning of CMT is based solely on linguistic 'evidence'. While this disregard garnered criticism, it also stimulated numerous experimental studies that found psychological or psycholinguistic support for the existence of conceptual metaphors which (partially) structure our understanding (see, e.g., overview in Gibbs, 2011). However, the claim

2. Of course, the finding that metaphor is actually a pervasive feature of ordinary language is also one of the major achievements of Lakoff and Johnson's work. In this introduction, though, we restrict ourselves to the aspects most important for the articles in the present volume.

that our cognition is partially structured by underlying conceptual metaphors also raised the question of how far these mappings are activated in online (i.e., in-the-moment, spontaneous, unconscious, real time) processing of verbal metaphors. That is, do we indeed need to activate the underlying mapping of ELECTRICITY IS A FLUID, for instance, when we encounter the linguistic metaphor *flow* in a sentence like "Electricity can *flow* through a battery" in order to understand the sentence?

For the present volume on making science accessible via metaphor, this is important. Much research has been devoted to this question and up to now, no conclusive answer has resulted. A number of experimental studies have found that people do *not* usually process conventional metaphors in language by activating cross-domain comparisons (e.g., Bowdle & Gentner, 2005; Gentner & Bowdle, 2001; Glucksberg, Brown, & McGlone, 1993; Glucksberg & McGlone, 1999; McGlone, 1996). Instead, when encountering conventional metaphors in language, we seem to make use of different cognitive mechanisms. Competing approaches to metaphor such as Conceptual Blending Theory (e.g., Fauconnier & Turner, 2008), Relevance Theory (e.g., Sperber & Wilson, 2008) or Class-Inclusion Theory (e.g., Glucksberg, 2001, 2008; Glucksberg & McGlone, 1999) have therefore been put forward to provide alternative accounts for verbal metaphor processing.

However, since metaphor in science deals not only with conventional metaphors but also with novel ones, the most important model of metaphor processing for the present purposes is perhaps the "Career of Metaphor" model proposed by Gentner and her colleagues. Their "career" model of metaphor resulted from a series of experiments which investigated the processing of metaphors with different degrees of conventionality (cf. Bowdle & Gentner, 2005; Gentner & Bowdle, 2001; Gentner et al., 2001). Their findings are in line with both CMT, which suggests that metaphor is processed by cross-domain comparison, and Glucksberg's Class-Inclusion Theory, which claims that metaphor is processed by categorization. That experiments support both CMT and the competing Class-Inclusion Theory may seem contradictory, but is resolved when considering the metaphors' different degrees of conventionality. Apparently, we process metaphors with different cognitive mechanisms, depending on the metaphor's degree of conventionality or novelty. Gentner and her colleagues maintain that *novel* metaphors are processed by cross-domain mappings (i.e., by comparison), the processing mechanism predicted by CMT (see Bowdle & Gentner, 2005). Once a metaphor becomes conventionalized, though, this changes. While early on during the process of conventionalization, a metaphor may still be processed by comparison (but can also be processed by categorization), the more conventional a metaphor becomes over time, the more likely it is to be processed by categorization. Finally, further on in a metaphor's "career" of conventionalization, its literal meaning is no longer evoked during online processing, which makes cross-domain mappings impossible.

The criticism that CMT has faced with respect to the psychological reality of conceptual metaphors, as well as the ensuing experimental studies of metaphor processing, offer some conclusions for our present volume. First, CMT is a valuable approach to metaphor when we try to uncover people's general understanding of scientific concepts based on linguistic metaphors, as there is ample evidence that underlying conceptual metaphors partially structure our thought. Prevalent understandings of scientific concepts are in fact what most of the chapters of this book present in order to raise awareness of these patterns and to draw attention to problems of some popular conceptual metaphors in science and science communication. Second, CMT also seems to be able to account for our immediate understanding of scientific concepts when encountering metaphors in discourse events, particularly in cases where these metaphors are less conventionalized and/or reinforced when presented together through more than one sensory modality (e.g., visual and verbal). A number of chapters in this book deal with such presentations of metaphor in science and science communication.

Apart from criticism about the psychological reality of conceptual metaphors, though, CMT has also been criticized for its use of decontextualized examples, instances that especially illustrate the metaphor in question and often quite isolated from context. Anecdotes and natural language extracts were frequently cherry-picked or examples invented (causing difficulties as described by Deignan, 2012; Deignan, Littlemore & Semino, 2013, p. 7). Moreover, the focus on uncovering underlying conceptual structures by postulating them based on linguistic examples can be seen as a methodological deficit, compounded by assertions that Lakoff and Johnson's (1980) linguistic evidence had not been collected systematically and had in fact often been obtained by introspection (see, e.g., Jäkel, 2003, p. 134). This has led to a general neglect of a metaphor's linguistic form as well as its communication or discourse function (Caballero, 2003, p. 145) because it omits the ways that each such metaphor is found to be expressed in actual language.

These problems, particularly of earlier studies adopting the CMT framework, have led to the emergence of a growing body of research that, while still acknowledging most assumptions of CMT, focuses on the forms and functions of metaphors in particular discourse events (e.g., Beger, 2011, 2016, 2019; Beger & Jäkel, 2015; Deignan, Littlemore & Semino, 2013; Semino, 2008, 2011, 2016; Semino, Deignan & Littlemore, 2013; Semino, Demjen & Demmen, 2016). Systematically documenting the varieties of a metaphor's expression in real discourse goes beyond anecdotal evidence to provide an empirical basis from which to establish the generalizability of metaphor research. Communication or discourse functions of metaphor are particularly important when considering how the use of metaphors makes science more accessible and are therefore also addressed in our volume.

To summarize this overview of Conceptual Metaphor Theory, we can draw three conclusions. First, CMT is a viable approach to study metaphor in science, as it allows us to uncover metaphors that structure common beliefs about scientific concepts. Second, in science and science communication, certain groups of metaphors such as novel metaphors are likely to be processed by cross-domain comparison, thus potentially making audiences aware of the source domains at play. While linguistic realizations of metaphors were neglected in early accounts of CMT, more recent metaphor studies have adopted corpus analysis, discourse analysis and other methodologies that examine the forms of metaphor occurring in actual language. Third, CMT was originally not explicitly concerned with the functions of metaphor in discourse, but a growing body of research that is at least loosely tied to CMT demonstrates the value of examining what metaphors do in specific discourse events.

All three aspects of metaphor – its conceptual structure, linguistic realization, and communication or discourse function – are essential when examining how metaphor can make science more accessible. The next Section (3.) therefore provides theoretical accounts of these three interrelated functions or levels of metaphor.

3. Interrelated levels of metaphor in making science accessible: Linguistic, conceptual, and discourse functions

We shall now describe how the formulations and insights introduced by CMT have been elaborated and clarified over decades. As mentioned, three levels or functions of metaphor have emerged in the scholarly literature (see, e.g., Steen, 2008). These are usually identified as linguistic realization (the language function), conceptual structure (the function of conceptualization or thought), and metaphor in communication (the discourse function). These three functions are closely interrelated, but in the following sections, we will summarize the main theoretical aspects of each individually, as far as this is possible.

3.1 Metaphor in language – the language function

As already mentioned, although CMT theorists were largely concerned with metaphor in thought, direct study of the psychological reality of metaphor in cognition was rare. Instead, language examples were carefully examined to uncover linguistic realizations of metaphors. The distinctions that became bases for subsequent study, and which are particularly relevant for metaphor in science, are the conventionality or commonness of metaphors, versus their novelty. Of importance also are similes and analogies. Each of these are now discussed.

3.1.1 *Conventionality and novelty*

The most basic distinction among metaphors in language is that between *conventional* and *novel* metaphors. One of the major accomplishments of Lakoff and Johnson's seminal work *Metaphors We Live By* is in fact that they pointed out the wealth of conventional metaphors in ordinary English. Metaphors in everyday communication are so conventional, so frequently encountered, that we are usually not aware of their metaphoricity.

Novel metaphors, however, stand out due to the juxtaposition of words usually not associated with each other, attracting attention and stimulating unexpected comparisons. For example, "Jellyfish hold a key position at the phylogenetic base of the metazoan tree" may at first sound like a statement of an animal's particular physical location. But this novel sentence metaphorically depicts metazoa (multi-celled animals) as ranging from rudimentary to more complex, locating the jellyfish accordingly.

The degree of novelty of a metaphor is not fixed but changes over time. As mentioned above (2.1.2), Bowdle and Gentner's (2005) model of metaphor describes the development of a metaphor (its 'career') from novel to conventional to 'dead'. That is, when a metaphorical expression enters the language, it starts as a novel metaphor. Thus, novel metaphors are those that we usually recognize as a metaphor. If the community of speakers adopts the metaphor in question, uses it frequently, it will become conventional over time. Once a metaphor is conventionalized, we normally use it without paying attention to its metaphoricity. Moreover, a metaphor possibly conventionalizes to the degree that its literal sense has become inaccessible to the speakers, because the word is no longer used with its literal meaning, only with its metaphorical one (ibid).

This process of conventionalization can also be observed in science. Often, scientists coin a novel (set of) metaphor(s) when they are faced with a new discovery that needs to be described verbally. For instance, in the 1940s, when Erwin Schrödinger tried to hypothesize about the then still largely unknown processes of protein synthesis, he created the novel metaphor of the "chromosome code script", which developed into the "metaphor of the genetic code" (cf. Knudsen, 2003, p. 1251).

Knudsen (2005) gives the example of "genetic translation" where RNA serves as a template in synthesizing protein and thus the RNA "language" is "translated" into protein "language".[3] The novel conceptual metaphor here might be expressed as TRANSLATING GENES IS TRANSLATING LANGUAGE. This is conveniently expressed as a simile – translation from the RNA template to the protein is like

3. Lumen, Biology for Majors, Module 10, DNA transcription and translation. https://courses.lumenlearning.com/wmopen-biology1/chapter/translation/).

translation from one language into another – and this form may assist one's cognitive process (discussed more fully below) of looking for and finding the parallels between genetic translation and language translation, thus aligning source and target features. This metaphor, itself part of a root metaphor, "the genetic code," was so successful in generating lines of scientific inquiry that it spawned clusters of related metaphors now at the center of molecular biology (Knudsen, 2005).

But, per the "Career of Metaphor" hypothesis already discussed above, an innovative novel metaphor, once its terminology becomes familiar and its meaning categorized, the metaphor that was originally suggestive and open in its possible meanings is found to narrow or close, becoming less and less generative of new scientific ideas. Its terminology becomes more and more conventional, established, part of the scientific lexicon and settled in its descriptive role. It may even seem entirely literal, very much like a fact (no longer meriting scare quotes or italics). In the case of the genetic translation metaphor, after inspiring highly innovative research hypotheses and years appearing in scientific articles, later was found largely replaced by the biochemical details of scientific experimentation (Knudsen, 2005).

This would be a metaphor in the final stages of its "career" – a 'dead' metaphor. However, while scientific metaphors such as the 'genetic code' may become 'dead' (i.e., non-metaphorical) to scientists specializing in the field, conceptual structures persevere even when the early source domains are forgotten. So these same metaphors may yet be perceived as (strikingly) novel by people outside the scientific area (cf. Giles, 2008, p. 148).

This is a crucial aspect for science communicators. Expressions, including technical terms, which specialists may no longer regard as metaphorical, can be perceived as novel metaphors, and thus be processed by cross-domain comparison (see 2.1.2 above), by an audience new to the subject. Therefore, science communicators could unwittingly use established metaphors of the scientific field that may have unexpected impacts on their audience's understanding of the scientific concept in question. On the other hand, science communicators are often quite aware of the 'dead' metaphors in their field, which allows them to capitalize on their metaphoric and explanatory potential by using these metaphors in a purposeful or deliberate way to guide their audience's reasoning. For the 'genetic code' metaphor, for instance, Knudsen (2003, pp. 1254–1257) found that in popular science articles, science communicators often pointed out and explained the 'dead' metaphors for their non-specialist audience in order to use these metaphors for explanations of the genetic code.

To conclude this section, consider how the distinction between conventional and novel metaphors in language is important for making science accessible. In reading the chapters of this book one may note instances of novel metaphors that guide scientific conduct by providing inference structure that, in turn, stimulates hypothesis generation; not only is the scientist aided but also other audiences gain insight into the topic of study and how science is carried out. Even when these once-novel metaphors, retained and used over time among specialists, have become conventionalized within a particular scientific community and lose their metaphoricity, they contribute terminology to the field. We have seen how this may not be the end of their metaphorical usefulness to science. It has been shown that, writing for a non-specialist audience, science communicators facilitate understanding of scientific concepts by reviving the metaphoric meaning of conventionalized terms.

Apart from novel and conventional metaphors, we can also identify other forms of metaphor in scientific language: *similes* and *analogies*. Some readers may wonder why similes and analogies are regarded as metaphors and not as completely different tropes. The following sub-section will explain the degree to which similes and analogies are considered types of metaphor. Furthermore, their influence on science will be pointed out.

3.1.2 *Metaphor in a wider sense: Similes and analogies*

Metaphor, simile, and analogy are figures that differ in their linguistic form. Simile, for instance, typically appears in the form "A is *like* B", while a particle of comparison does usually not occur in the linguistic form of metaphor. There is ample evidence that metaphor and other tropes such as similes differ not only in the way they are processed (see, e.g., the overviews provided in Colston & Gibbs, 2017, pp. 462–463; Gibbs & Colston, 2012) but also in the way they are used in discourse. Thus, it is not surprising that metaphor, simile, and analogy are often considered to be distinct and that many scholars believe that similes and analogies are not simply types of metaphor. While we generally agree with these distinctions, we also concur with scholars (see, e.g., Ortony, 1993) who point out that metaphor, simile, and analogy bear important similarities based on which some researchers regard simile and analogy as special types of metaphors.

The important aspect shared by metaphor, simile, and analogy is the underlying cross-domain mapping, even if this mapping is not necessarily activated in the moment the figure is processed. Similes, with two distinct domains, most obviously involve a cross-domain mapping, since two unlike things are explicitly compared to one another in expressions or sentences such as "Science is like a glacier" (Steen, 2011a, p. 51). We are disposed to accept the argument that similes and metaphors belong to the same category of underlying cognitive processes, despite the fact that they differ in their linguistic realizations (explicit comparison in case of simile and implicit comparison in case of metaphor), online processing, and usage.

A similar argument can be made for any form of longer comparison that involves a cross-domain mapping, as is the case for numerous *analogies*. Analogies are also important for science, as we find many influential analogies in conducting and communicating science. For instance, the reader is probably familiar with the 'solar system' analogy for the description of atoms in chemistry or the 'factory' analogy to describe cells in biology.

Similes and analogies deserve special attention here – not only because they are an established linguistic tool in science, but also because they can impact one's reasoning just by virtue of their linguistic form. Such direct comparisons function similarly to novel metaphors (also cf. Steen, 2011b). The direct comparisons found in similes and analogies are likely to have a greater impact on the audience's understanding of a scientific concept than conventional metaphors because the latter no longer draw attention to a comparison with the source domain. The conceptualization of similes and analogies is discussed further in Section 3.2, below.

Metaphors in language can point to underlying conceptual metaphors that influence thought and generally structure reasoning and cognition. In the next section, a more detailed account of conceptual metaphors, that is, metaphor in thought, is given.

3.2 Metaphor in thought – the conceptual function

In examining the conceptual function, or metaphor in thought, one asks what a metaphor means and how it influences cognition or reasoning by offering a conceptual structure for understanding. Above (2.1.1), we mentioned that the conceptual function or level of metaphor has been the primary interest of the founders of CMT. The central tenet of metaphor in thought as depicted in CMT is a mapping from aspects of the more concrete or more familiar source domain to the more abstract, complex or unfamiliar target domain. Thus, in trying to understand a domain that is usually more abstract or unfamiliar to us, such as TIME or LOVE in everyday life, we make use of a domain that is better known, for instance MONEY or JOURNEY (cf. Lakoff & Johnson, 1980). What makes mapping from source to target domain possible is a set of correspondences between the two domains. The existence of a conceptual mapping between two domains is usually assumed if we find ample evidence in language, that is, if there are numerous metaphorical expressions which systematically reflect the given mapping. When such evidence exists, the metaphor would be referred to as a conceptual metaphor, customarily designated in print by small capitals (e.g. LIFE IS A JOURNEY).

Examining bodies of natural language for evidence of conceptual metaphors and their mappings is a painstaking process. As already mentioned above, the early researches in CMT relied on the reading of selected texts and subjectively identifying metaphors, then noting word use that implied what mappings are active. We already outlined criticisms of CMT, above, arising from this early methodology.

The metaphors found in this way may too often conform to the researchers' ideas and expectations. Inherent unreliability in such procedures inspired more rigorous identification methods to identify realizations of metaphor in language. The first widely recognized metaphor identification procedure, MIP, was published little more than a decade ago, by the Pragglejaz Group (2007). Soon after that, MIP was revised into MIPVU by Steen and his colleagues (Steen et al., 2010) who accommodated the procedure to less common but important types of metaphors, such as "direct metaphors" (that guide an audience explicitly to make a comparison between source and target domains, as occurs with similes). This trend takes into account genre and particular communicative aspects of metaphor in use (see Deignan, Littlemore & Semino, 2013; Semino, 2008).

Also, an array of corpus methodologies appeared that exploit computer software designed to produce concordances (e.g. Cameron & Low, 1999). Automated methods allowed metaphor researchers to comb large bodies of text for all manner of metaphors that might be found, accurately determine their frequencies, co-occurrences with other metaphors, and to see the natural variations in form. These methods helped to document occurrence of conceptual metaphors in various discourse types, quickly finding expressions in language which reflect a given metaphoric mapping. The availability of these more objective and rapid methods has clearly influenced the studies reported in this volume, elucidating a wider variety of metaphors, making clearer their degree of conventionality or novelty.

For metaphor in language, as discussed above (3.1.1), we differentiated between conventional and novel ones. The same basic distinction also holds for conceptual metaphors, but when metaphor researchers identify conceptual metaphors they declare their interest in how people cognitively process and make sense of the metaphor. A conventional conceptual metaphor source domain is one that is frequently shared in the particular language community and readily understood. This is because well-known elements of the source domain remain orderly and stable based on known semantic representations – "well-behaved mappings of words to meanings" (Veale, 2014, p. 53). For such conventional metaphors, mappings are automatic, rapid and largely unconscious, even though there is evidence that many complex embodied and conceptual processes are involved (Gibbs & Chen, 2018). Such well-behaved semantic representations have also been referred to as involving property-matching and analogy (mapping of structures in terms of relations) or category inclusion (target is member of a category of which the source is a prototype) (Gentner & Bowdle, 2006). When features of the source domain are frequently encountered, becoming familiar, even prototypical, these "coded meanings foremost in our mind" are said to be "salient" (Giora, 2008, p. 10) and easily accessed mentally, readily activated and mapped to the target domain.

Psycholinguistic studies attempt to understand the cognitive processes that enable metaphor conceptualization. While avoiding here the extensive theoretical debates about these conceptualization processes,[4] there is good evidence that certain metaphors are processed more easily than others, particularly direct, conventional metaphors that are apt, familiar and frequently used (Ashby et al., 2018 offer a review), and for individuals with stronger working memory and inhibitory control (Holyoak & Stamenković, 2018). They may be comprehended as well and as quickly as literal statements (Gibbs & Colston, 2012). But when metaphors are put in the surface form of simile (using "like" or "as"), an audience is linguistically cued to mentally compare the target domain to the source, potentially predisposing the mapping process. Metaphor, on the other hand, requires a cognitive search for previously formed correspondences (Gentner et al., 2001). Where psycholinguistic studies use eye-movements as indicators of cognitive processes, similes appear to work better than simple metaphors, yet much seems to depend on the details of the experimental tasks involved (Ashby et al., 2018).

The cognitive processing of both metaphors and similes have been described, starting with Aristotle, as analogical in nature – an ability to reason based on the relations between two different entities or domains (cf. Holyoak & Stamenković, 2018). Analogies have been said to organize information, make it more concrete, enable more efficient search and retrieval of source domain information from long-term memory, help visualize the source domain and perhaps assume the form of a logical argument (Shapiro, 1985). Although explication of an analogy may at first sound like a simile (e.g., a membrane is like a cookie), note is made of various similarities (a membrane has two layers of lipids [like Oreo cookie wafers]) and how these features relate to each other (layers are separated by a center [of white cream]).[5] As additional correspondences are given, the analogy goes beyond comparison based on similarity or resemblance of surface properties as occurs with similes, and promotes the deeper and more thorough mental process of mapping structural relations among source features (Kretz & Krawczyk, 2014, offer a review). This heightened attention to the source domain can put it at the forefront of the mind, make it more salient, easier to access and map to the target domain, as further discussed below regarding novel metaphors. Extended analogies are widely used in science to explain theories and instruct students, as the numerous examples in this book illustrate.

Because of their familiarity and physical realness, scientists may prefer conventional metaphors when they actually choose them consciously; early twentieth

4. Termed *Metaphor Wars* by Gibbs (2017), especially Chapters 4 and 5.

5. Example from http://www.metamia.com/analogize.php%3Fq%3Dq.

century physicists used metaphors that explained physics and became theory constitutive (Brown, 2003, p. 85; Gentner, 1982). But scientists so often do not choose them consciously (Knudsen, 2015; Smith, 2015). Because of their near-automatic use without awareness, science communicators can end up using metaphors that, while helpful in certain respects, are unintentionally confusing, even misleading. We see examples in the chapters of this book.

Novel metaphors, on the other hand, diverge from the conceptual norms and stereotypes that govern the meanings of conventional conceptual metaphors. They map source domain features that are not (yet) associated with the target, perhaps initially seeming 'unmappable'. Metaphor scholars have studied novel metaphors within artistic domains and poetry (such as Lakoff & Turner, 1989), but they also occur frequently in science, as chapters here illustrate. The meaning of novel metaphors depends on the process of somehow aligning source domain elements with target domain elements (Gentner et al., 2001) even though this may not happen easily. This alignment process is inferential and interpretive and occurs spontaneously in more of what has been called a "top-down" fashion (Giora, 2008, p. 144).

We will review how metaphor conceptualization and comprehension depends heavily on what kind of metaphor source domain is involved – those based broadly on bodily experience or what might be called social gestalt; also (and related) whether a source domain is concrete or relatively abstract. We will now describe in more detail two types of conceptual metaphors widely used to provide access to phenomena not directly perceivable and their relevance for making science accessible: *embodied metaphors* (3.2.1) and *socio-cultural metaphors* (3.2.2); this is followed by four attributes of conceptual metaphors that feature in chapters of this book and that will be of concern to the science communicator: source domain background knowledge (3.2.3), target domain background knowledge (3.2.4), how abstract a source domain might be (3.2.5), and combinations of metaphors (3.2.6).

3.2.1 *Embodied metaphors*

Research in this vein might be typified by focusing on some widely used and embodied source domain based on physical bodily experience; thus metaphor researchers term it 'embodied', such as journey (SCIENCE IS A JOURNEY: "biology progresses step-by-step") or movement (CHANGE IS MOVEMENT: "the theoretical viewpoint shifted"). Metaphor researchers then explore the various mappings of these rich source domains to reveal the conceptual structure that can be transferred to chosen target domains. We see, for example, that evolutionary biological processes are metaphorically conceived as a journey; when one maps features of a journey to biology, the evolution of a species can be characterized as following a path, encountering obstacles, pausing at intermediate points to re-orient and perhaps adjust its direction. A source domain such as JOURNEY is so common, one can easily find other target domains that it elucidates, such as LIVES, CAREERS, ECONOMIES; even DECORATING A CAKE can be conceptually structured with the same journey features.

In the course of early metaphor scholarship this focus on the conceptual structure of bodily movement showed that a relatively small number of metaphor source domains (such as the HUMAN BODY, HEALTH AND ILLNESS, ANIMALS, PLANTS, SUBSTANCES, OBJECTS, MOVEMENT, MACHINES, FORCE MECHANICS, CONSTRUCTIONS, CONTAINERS, GAMES AND SPORTS; cf. Kövecses, 2002; Liu, 2016) provide the form, logic, direction and constraints when thinking about a broad array of target domain activities, projects, theories, and understandings in science and everyday life. When combined, such metaphors complement each other or blend to shape understanding of highly complex topics (as discussed later).

When metaphor researchers have focused on the conceptual function of embodied metaphor, they have usually emphasized conventionality, unconscious use, concreteness, and complexity of source domains. Embodied source domains figure in research reported in this volume and their power in making science approachable is clearly shown.

3.2.2 *Socio-cultural metaphors*

Apart from conceptual metaphors whose source domains heavily draw on our physical experience of the world, we also find those that draw on a different class of experiences as human beings: our social or cultural experiences. These source domains exploit our knowledge of familiar habits of action such as established work and play activities, governing practices, crafts, or codified skills captured in writings, products, symbols, or other tangible, material objects (cf. Grassby, 2005). *Socio-cultural metaphors* may seem to be vague compared to *embodied metaphors*. However, they need not be vague if they are understood in terms of actual, concrete experience. Because socio-cultural metaphors are not so much experienced bodily, as culturally lived, they can depict interactions of separate entities at a higher macrocosmic level. Socio-cultural source domains can be complex gestalts that are culturally learned, characterized in terms of generic, structural dimensions as conventionally experienced (cf. Lakoff & Johnson, 1980, p. 202). The shared social experience of science communicators and their audiences enables them to form common gestalts or image schemas, becoming the basis for metaphoric source domains. Because gestalts arise naturally in social experience, they seem conceptually whole and coherent. For example, the experience of working with others in a group can provide an experiential basis for a conceptual metaphor source domain such as TEAMWORK that explains coordinated action among individuals and implies or predicts intention to achieve a goal.

Another example is geologic time (such as the age of the earth or when humans first appeared) that can be macroscopically viewed as the metaphor of a single calendar year; mapped accordingly, humans appeared during the afternoon of December 31st. The calendar year is understood primarily by daily living in a culture where experience yields a stable, conventional source domain for geologists and anthropologists to use in teaching students or the public about the place of humans in the vast expanse of geologic time. Other examples include the use of the domain of SECRET CODES or CIPHERS to describe and explain the process of protein synthesis, as mentioned above, or the use of religio-cultural expressions to characterize synthetic biology as "playing God" or "creating life" not only to inform the public about this new and noteworthy field but also to shift public perceptions (Braun et al., 2018).

We see in this volume several examples of how biological processes are metaphorically conceived as social phenomena, and mappings from a socio-cultural source domain are made to microscopic biological entities, giving them the executive capacities to make decisions, plan, gather resources, identify objectives, pause at intermediate points to re-orient. Just as cells combine to form differentiated organs with distinct functions at a macro level, socio-cultural source domains can be used to summarize and characterize these biological functions.

The demands of cognitive processing of metaphor, how it works for different types of metaphor and audiences with varying degrees of source domain familiarity, is a rich area of investigation. Evidence indicates that metaphoric language induces a cognitive, embodied simulation of what it would be like to experience the source domain, where the motor cortex appears to be recruited, displaying patterns of neural activation in parallel to that of language comprehension (Gibbs & Matlock, 2008). Still, such an embodied simulation would depend on one having had the relevant background, that is, the direct experience of the source domain (cf. Jamrozik et al., 2016).

3.2.3 *Source domain context or background knowledge*

Saliency will clearly depend on the context in which the metaphor is used and the degree to which context for the science communicator coincides with context for the audience. Understanding what a science communicator means depends heavily on context, including the circumstances in which the metaphor is used (cf. Carston, 2010).[6]

6. But note that "salient" or "coded meanings foremost in our mind" are challenged by Veale (2014) who asserts that established conceptual metaphor theories rely on these conventional conceptual mappings, not taking into account the empirical distributions and hierarchies of concepts of a particular language community.

Metaphors are introduced by science communicators in the first place to describe and explain scientific phenomena which are often complex and that cannot be perceived directly. How best can these metaphors enhance audiences' ability to think about and understand these phenomena? Often ignored is the rich context and much of the pragmatic knowledge that gives more abstract or less common metaphors their complex, inferential ideation (Holyoak & Stamenković, 2018). Giora (2008) has found that availability of meaningful source domain context (both local and global), coherence of this context, including when during metaphor processing this context can be accessed – are of key importance to assure efficient and full understanding; also important is contextual details of the situation in which the metaphor is applied (Carston, 2010; Oļehnoviča & Liepa, 2016). Case studies of metaphors in science, including some in this volume, illustrate the extent to which science communicators will go to provide adequate context for the metaphor source domain; the successes and failures are instructive.

3.2.4 *Target domain context or background knowledge*

It is not only the context of the source domain that is essential. Inadequate target domain background knowledge is also an issue. Occasionally scientific metaphors may be expressed with so little regard that the audience remains ignorant or confused about what target domain is being discussed, so a metaphor is less likely to help. This would occur if the education of the audience is far below the level assumed by the science communicator, or reference to the target domain is made using unfamiliar terms. Example: "A third-generation leptoquark might couple with a tau and a bottom quark" (Letzer, 2018, p. 1). This seems to invoke a sexual metaphor or perhaps one of human social relationship, but the reader needs more information to make use of such metaphors. An audience member would be obliged to look for more instances of "leptoquark" as a possible target domain, and "coupling" as a possible source, and thus to see what other, more comprehensible terms or information are associated. This co-location approach is laborious, unlikely for a science audience, and therefore such a metaphor will not fulfil its function of making the scientific subject matter convenient to understand.

But something similar has been used in scholarly lexical analysis where the target domain is not a thing, substance or object, but a process, or where many conceptual metaphors are simultaneously employed, and the lexical instantiations of target and sources are not co-located; machine searches for source domain key words produce clusters, suggesting target domains of interest (Lederer, 2016). Sometimes the target domain of metaphorical language is not just obscure, but absent. It is not unusual to find metaphors in poetry or allegorical prose where no target domain is explicitly instantiated. Kövecses (2002, p. 45) illustrates this with a poem by Emily Dickenson where several conventional metaphor source terms describing love are found in combination, the target is never named but the audience assumed able to make sense of what is said; science writings are very unlikely to rely so much on an audience's inferential powers. Consequently, many authors in this volume take pains to familiarize the audience with the nature of likely unfamiliar target domains before presenting scientific metaphors.

3.2.5 *Abstract source domains*

Our review of the central tenets of CMT, above, presumed that a source domain-to-target domain mapping involved a source domain that is concrete or more familiar and a target domain more abstract, complex or unfamiliar. What happens if a metaphor source domain is not actually concrete, but instead the language used is abstract, perhaps vague? If a metaphor fails to evoke a reliable experiential gestalt shared by science communicator and audience, the structure of the source domain (not only which elements are included in the source domain, but also their interrelationships), and the semantic network in which it is embedded, will not reliably be mapped to the target. If the source domain is not properly understood or even familiar, misunderstanding or misinterpretation occurs (Cameron, 2003).

Such instances may involve a reversal of the more common relationship found with conceptual metaphors as mentioned above, that is, where the source domain is structured by concrete sensory or socio-cultural experience in order to facilitate understanding of a more abstract target domain (Gentner, 1982; Kövecses, 2005; Lakoff, 1993, p. 229). In science and, in particular, the scientific topics reviewed in this volume, this reversal can sometimes be found. Metaphor source domains might be said to exist on a continuum of abstraction (Borghi & Binkofski, 2015) such that, to varying degrees, audience members lack grounding of some metaphors in actual experience.

If the goal is to enhance access to the scientific topic, and if abstract source domains are somehow necessary or unavoidable (such as when specialized models or mathematics is used), the science communicator is obliged to give special emphasis to context and background information. Failing this, where an audience has been insufficiently exposed to source domain structure or has learned only abstract principles, the features of the source domain remain unknown and can't readily be aligned and mapped to the target. Deliberate review of the correspondences between source and target, sometimes attempted in school situations, can help.

Note how mathematics teachers attempt to assist this alignment process in teaching the balancing of equations by introducing the analogy of an actual balance scale ("balancing equations is like balancing a scale," Richland et al., 2007, p. 1128); students learned better when the teacher manipulated the scale and pointed out the correspondences between source domain (balance scale) and the target domain (algebraic equation) with gestures and explanations. This illustrates how cognitive processing demands might be reduced, requiring less struggle as students search long-term memory regarding the source domain and keep mapped features in working memory while attempting to understand (Richland et al., 2007). Additional insights about conceptual access to abstract source domains comes from neurological evidence that not only conventional and concrete source domains may reactivate embodied sensorimotor simulations (as mentioned above), but that abstract concepts can do so as well (see Jamrozik et al., 2016).

3.2.6 *Metaphors in combination*

For an unfamiliar topic or target domain, not one, but multiple metaphor source domains are likely to be required in order to cover all important facets. The shift in metaphor research methodology to corpora analysis makes it easier to study how conceptual metaphors, rather than employed singly, actually are used in combinations. Each separate metaphor contributes to some understanding and none alone is sufficient. Metaphor structure, and thus comprehension, can be significantly altered in such cases. For example, conventional but conceptually distinct metaphors (ORGANIZATION IS PHYSICAL STRUCTURE and THE STATE IS A FAMILY) are found to serve especially well in explaining politics (Perrez & Reuchamps, 2015). But how might they relate not only to the target domain, but to each other? Chapters in this volume report various ways that scientific metaphors are used together.

Of importance to conceptual metaphor scholars are such matters as how combinations of metaphors could produce novel forms (Lakoff & Turner, 1989). Some metaphor combinations include background metaphors, necessary for understanding but not dominant (Blumenberg & Savage, 2010). Primitive or primary metaphors that complement each other can combine into complex ones (Grady, 1997; Lakoff & Johnson, 1999; also see Smith, 2009), form compounds of primary and cultural metaphor, metonymy, and literal propositions (Yu, 2008), or consist of a core metaphor with conceptually integrated sub-mappings (Veale & Keane, 1992). There may be scenarios or mini-narratives (Musolff, 2006), clusters or chains in text (Koller, 2003), with elements that range from fully consistent to semantically divergent and clashing (Charteris-Black, 2005). Two or more source domains may interact or blend (Fauconnier & Turner, 2002) or form hybrids in film or photo to serve explanatory purposes (Forceville, 2016).

When an explicit scientific analogy is chosen, it is not simply to change point of view or introduce an unfamiliar perspective, but to instruct students on a science subject that may be complex and multi-faceted. For example, to explicate the catharsis theory of aggression a psychology professor metaphorically uses an overarching conceptual metaphor, AGGRESSION IS FLUID IN A CONTAINER, then elaborates this into an analogy using additional direct metaphors that realize sub-mappings such as aggressive impulses are drops of water entering a tank and aggressive impulsivity is weight/pressure of water building up in tank, then extending the analogy further with other direct and indirect metaphors that are conceptually coherent (Beger, 2011). But this analogical explanation omits the use of (other) conventional metaphors for aggression such as heat, and literal accounts of aggression such as attitudes or emotional instability. So the professor has chosen a conceptually coherent combination of metaphors to best enable students to think through the chosen theory, postponing more comprehensive and accurate understanding. This book illustrates numerous other ways that instructional analogies, involving combinations of direct and indirect metaphors, trade scientific accuracy for coherence of understanding.

Gibbs (2016) brings together many points of view regarding combinations of metaphors, showing that cultural knowledge, assumptions, beliefs, reasoning, ancillary knowledge, and multi-model mixes are all important. Despite the potential for interference or confusion, multiple metaphors in combination do regularly operate successfully without clashes of meanings or images. This has inspired others to investigate how metaphors are activated in particular contexts, for example, how juxtaposing multiple, conceptually clashing source domains makes one of them more important or salient than another (Gibbs, 2017), how various signals such as "figuratively speaking …", hedges ("kind of", "if you will"), and "scare" quotes direct audience attention while mixed metaphors set up deliberate contrasts between conceptually disparate source domains (Nacey, 2013). In this volume, we see numerous examples of these metaphor combinations that appear to re-conceptualize, recontextualize, or produce alternative perspectives on a topic.

So far, we have seen that both the linguistic and the conceptual functions of metaphor are important for the conduct, description and explanation of science. However, there is another level at which metaphor operates, the *discourse function* or *metaphor in communication*. Above (3.1), we pointed out that metaphor in language is largely concerned with its linguistic form or conventionality, which can have effects on how the metaphor is processed during online comprehension. In the present section, we drew attention to the conceptual structure or metaphor in thought, pointing out the importance of mappings and differences of various types of source domains which provide rich knowledge to be made use of when communicating science. The next Section (3.3) considers a metaphor in its discourse context and asks how a given metaphor is supposed to operate in science communication. For instance, is the metaphor intended to *explain* a scientific aspect or is it perhaps used in order to shift the audience's attitude towards a scientific phenomenon and thereby be *persuasive*?

3.3 Metaphor in communication – the discourse function

Over the last twenty years, metaphor scholarship shifted to a more discourse-based methodology, which makes it possible to document in more detail the particular forms and meanings that metaphors take in authentic communicative situations. This approach has revealed variations not so apparent when the process of metaphor conceptualization focused primarily on isolated examples. More attention has therefore been brought to metaphor's communicative function.

Metaphor starts by sharing the communicative functions of language generally, such as expressing facts, opinions, theories, the truth or falsity of propositions and logic. Also like other forms of language, metaphor will provide contextual frames, attract attention, express emotions, evaluate, motivate and inspire. As figurative language, metaphors have long been viewed as communications tools, even when primarily seen as adornments or embellishments to literal language. They can make a difficult topic easier, aid memory, and draw attention to key aspects of the subject matter or target domain. Being more compact, metaphors often provide a means to communicate quickly and efficiently compared with literal language. They can express phenomenal experience that may be inexpressible literally (e.g., scientifically unobservable phenomena such as subjective mental states are often depicted as things that move the body, pressing or pulling: THOUGHTS ARE OBJECTS THAT PASS THROUGH SPACE, EXERT FORCE). They liven up the communication, do so richly, vividly and clearly (Gibbs, 1994), giving metaphor "an indispensable communicative function" (Ortony & Fainsilber, 1987, p. 183).

When metaphors are considered in context, rather than being isolated, the Wittgensteinian notion of "meaning as use" (Määttänen, 2005), when applied to scientific metaphor, asserts that the science writer communicates purposefully to achieve an intended effect, including any or all of the communicative outcomes just mentioned in the preceding paragraph, in the particular setting and context. A proper theory of metaphor, especially a cognitive linguistic one, must provide insight into the communicative dimension of metaphor. Thus, it is not surprising that Steen (2008) proposes an enriched model of metaphor by explicitly incorporating the communicative function. A review of communicative functions that inevitably emerge from our earlier theoretical discussions of CMT (2.1), metaphor in language (3.1), and metaphor in thought (3.2) is appropriate before continuing.

3.3.1 *Review of metaphor in communication as implied in theoretical discussions above*

Although Conceptual Metaphor Theory (CMT) does not explicitly state a communicative function for metaphor, it defines metaphoricity as the information transfer from source to target domains via correspondence mappings. Conditions for successful mappings are explored. Anyone interested in enhancing the communicative potential of metaphor will attend to these conditions so as to afford systematic inference structure to assist the audience's reasoning. Investigations stimulated by CMT into correspondences that map or fail to map, and into the possibility of category formation as an alternative explanation, lead in turn to the Career of Metaphor formulation. This gave insight into problems in understanding scientific and other concepts that depend on a metaphor's more frequent use and declining novelty over time. It led to strong lessons for when and how metaphor might best be communicated to a given audience and misleading inferences avoided.

In discussing the language function of metaphor, the distinction between conventional and novel metaphors highlights communication issues. Conventional metaphors are used unconsciously but nonetheless frame the communication of scientific descriptions and explanations. Novel metaphors more explicitly communicate source domain features intended to educate the audience. Further work by metaphor researchers to understand the Career of Metaphor prompts science communicators to know where in its career a chosen metaphor is, its frequency of use and status among specialists as a theory constitutive construct that might stimulate new hypotheses or become a conventionalized term. By observing this, one can tailor communication to either close access to the source domain by essentially ignoring its structure and treating it as a literal, technical term, or foregrounding the source domain if the audience can benefit from further explanation of the scientific phenomenon. Using similes and analogies prompts audience attention to the mappings of source domains to targets in order to have a stronger impact on reasoning. From this, science communicators learn that the wrong choice of metaphor can communicate unintended interpretations. This, in turn can motivate them to make intentional or deliberate choices.

Understanding of the conceptual function of metaphor was shown above to benefit from more rigorous methodologies. Corpus and discourse analysis methods reveal details of metaphor forms in actual language and this is helpful in sensitizing science communicators to ever-present conventional metaphors alone and in combinations, the ways they nest together or form hierarchies, blend, mix in narratives, and the effects of multi-modal combinations found in advertising and instructional material. Varied examples of both embodied and social metaphors were supplied by the more comprehensive discourse-based methodologies. Science communicators, when consciously choosing a metaphor or simile, will naturally want it to be salient. They may enhance saliency by extending similes into analogies that highlight structural aspects of a source domain and promote better cognitive alignment with the target. The study of saliency shows the importance of contextual and cultural knowledge, assumptions and beliefs. This includes target and source background knowledge an audience must possess to put a metaphor "foremost in our mind," easily accessed mentally, readily activated and mapped to the target domain. Multiple metaphors in combination, despite the potential for interference or confusion, are seen in actual discourse to regularly operate successfully. Such real-life examples show what might be specially created in science writing and other genres to communicate science.

Of interest are the purposes that science communicators have in mind when they use particular metaphors. For instance, in science pedagogy, metaphors might be chosen in order to *explain* a scientific concept whereas in science popularization, we might find more diverse reasons to choose certain metaphors, such as *convincing* the public or *evaluating* a scientific concept. Add to this an intention to shift perspective, contribute theory-constitutive structure, or simply to draw attention, persuade, convince, promote ideological agendas or propagandize.

We can see, then, that scholarly work concentrating on CMT, language and the conceptual structure of metaphor have brought forth communicatively relevant factors in metaphor use. Knowing in more detail how metaphor actually occurs in discourse allows its communicative efficacy to be evaluated. What particularly stands out is the importance of deliberation, awareness or consciousness in influencing choices in metaphor use. So the elevation of *communication* as a third fundamental function of metaphor, and a focus on *deliberate metaphor*, seem to be natural outcomes of these developments.

Steen's recognition of the communicative function of metaphor (e.g., 2008, 2010, 2015) focuses on a distinction between 'deliberate' and 'non-deliberate' metaphor and this has generated considerable discussion and controversy. In the following sub-sections, we will first briefly outline his notion of 'deliberate metaphor' (3.3.2) and then we will point out difficulties with this concept and cite alternatives (3.3.3).

3.3.2 *The concept of 'deliberate metaphor'*

The value of deliberate metaphor in communication has been studied and partially confirmed by Beger (2019) and Reijnierse (2017), who applied improved methods of distinguishing potentially deliberate metaphors from non-deliberate ones. Their studies show that deliberate metaphors are important tools for shifting an audience's perspective to accord more to that of the metaphor's source domain. The effectiveness of this perspective-changing function of deliberate metaphor depends on the particular context and purposes of the participants of a given genre or sub-genre. For the genre of science pedagogy in particular, Beger (2019) shows that deliberate metaphor fulfills important explanatory, but also affective, functions in college science lectures despite certain limitations and problems.

Steen adds the communicative function of metaphor (e.g., 2008, 2010, 2015, 2017a) to CMT's existing two-dimensional (language and thought) model of metaphor. In so doing he emphasizes 'deliberate metaphor', distinguishing it from 'non-deliberate' metaphor in communication in a binary fashion, so every metaphor is seen as either deliberate or non-deliberate. A deliberate metaphor is said to show evidence of a writer or speaker's attention to and, in turn, draws audiences' attention to the metaphor's source domain (see, e.g., Steen, 2017b, pp. 281–284). Some of the types of metaphors we outlined above (3.1) almost automatically fall into the category of deliberate metaphors, according to Steen's definition. If a metaphor is novel for a particular addressee (see 3.1.1), for instance, he or she will probably have to attend to its source domain in order to make sense of the metaphor in its context. Other types of metaphors that seem to require attention to their source domain due to their linguistic form are similes, analogies or other forms of metaphorical comparisons (see 3.1.2). Since these types of metaphors involve explicit comparisons between the source and the target domain, the source domain has to be attended to in order to resolve these comparisons (cf. Steen, 2010, p. 56).[7] Other types of metaphors (conventional ones, for instance) can, of course, also be used in such a way that they require attention to the source domain and would hence be classified as deliberate metaphors in Steen's model. However, they do not simply draw attention to their source domains by themselves. Some other linguistic or contextual features would be required.

One of Steen's central arguments is that attention to the source domain gives deliberate metaphors a clear communicative function. Yet he states this attention may or may not be conscious on the part of the language user (see, e.g., Steen, 2015, p. 69). Many readers may now wonder how a person can pay attention to a metaphor's source domain without being conscious of it. This seems contrary to the very notion of 'deliberate metaphor' and furthermore implies that 'non-deliberate metaphor' requires no attention and thus lacks any communicative function. So, by this account, the binary distinction between deliberate and non-deliberate metaphor would relegate the bulk of all metaphors in language – non-deliberate metaphors – inferior to the relatively small group of deliberate metaphors. Problems like these lead us to our brief discussion of difficulties with the concept

7. Note that in his model of metaphor, Steen (e.g., 2010) subsumes similes, analogies, and other forms of longer metaphorical comparisons under the label 'direct metaphor'. However, since this label is less informative than naming the tropes (e.g., *simile* or *analogy*) and not of importance for the contributions in this volume, we will refrain from outlining Steen's distinction between 'direct' and 'indirect' metaphors. The interested reader is referred to Beger (2019, Chapter 2.2.1) for a summary and critical discussion of this binary distinction made by Steen.

of deliberate metaphor and alternative approaches to discourse or communicative functions of metaphors.

3.3.3 *Problems with 'deliberate metaphor' and alternative concepts*

Besides a lack of empirical evidence that audiences actually attend more to the source domain of so-called deliberate metaphors (Gibbs, 2015), in science communication a given metaphor is not necessarily either deliberate or non-deliberate. As we explained above (3.1.1), metaphors that are quite conventionalized among specialists of a scientific discipline, that is, no longer considered metaphorical, might be completely novel for non-specialists or novices in the scientific field. When an audience perceives a metaphor as novel, it inevitably attends to the source domain, which (by Steen's account) turns that metaphor into a deliberate one. Thus, any given technical term in science communication based on a conventional metaphor might be both a *non-deliberate* metaphor (for specialists in that scientific community) and a *deliberate* one (for non-specialists).[8] Furthermore, especially with metaphorical technical terms, non-specialist audiences of science popularization may gradually become familiar with the metaphors of the respective discipline. Therefore, any given metaphor can potentially change from being deliberate for an individual to becoming non-deliberate to that individual over the course of a discourse event. We see, then, that Steen's concept of 'deliberate metaphor' – a concept that is supposed to elucidate a metaphor's communicative function – can account neither for individual differences among discourse participants nor for the dynamics of discourse events.

However, alternative approaches exist that can help. One of them is Müller's 'dynamic view of metaphoricity' (Müller, 2008, 2017), which is in line with the dynamical systems approach to metaphor by Cameron and Gibbs (Cameron, 2010a, b; Gibbs & Cameron, 2008). In this approach, metaphoricity "is activated dynamically in an interaction – over the course of a discourse event and to varying degrees" (Müller, 2017, p. 300). Since metaphor activation is described as quite similar to 'deliberateness', that is, "putting metaphoric meaning into the foreground of attention", Müller's dynamic view might be able to retain the advantages of Steen's concept of 'deliberate metaphor' (recognizing that metaphors can in fact draw attention to their source domain but often are not used in that way) while disposing of the difficulties described above.

Charteris-Black (2012) also takes issue with Steen and introduces the notion of 'purposeful metaphor'. This notion is not connected to aspects of metaphor processing such as attention but instead considers three important aspects of

8. See Beger (2019) for discussions of specific examples of such cases, for instance in Molecular Biology lectures.

metaphor in discourse: a metaphor's "intention or idea, metaphor use or plan, and rhetorical outcome or social impact" (Charteris-Black, 2012, p. 19).

Additional examples of metaphoric communications in science can be found that raise difficulty with Steen's strict definitions of 'deliberate metaphor.' Consider some, initially introduced as novel labels drawing attention to a source domain and provoking cross-domain mapping, then used casually and non-deliberately once they become familiar. As conventional, indirect metaphors, used repetitively, consider the degree to which these familiar usages channel thinking: genetic "blueprints," ecological "footprints," "self-regulating" systems, "invasive" species, "agents" of infectious disease, "superbugs," "arms races," or "food chains". These deeply entrenched indirect metaphors make complex scientific topics simpler by seeming to encapsulate obvious qualities of the target domain while at the same time they are *ideological*, *constraining* of new thinking, and quickly debunked by current science (Taylor & Dewsbury, 2018). Referring to certain parts of a city as "urban blight" versus "urban communities" encodes a stereotypic notion that organizes information and attracts attention to different aspects of a problematic situation: tear down and replace vs. nourish, reinforce and strengthen (Schön & Rein, 1994). When such generative metaphoric terms become popular and conventional they contribute more to ideology than science.

But the impact of such examples cannot be known until we see how they are deployed in context; in the professor's lecture example, above (Beger, 2011), such terse, indirect metaphoric labels and terms had been deliberately introduced in combination with a direct, deliberate, overarching metaphor, producing a multifaceted analogy that works to explain scientific theory (especially in a lecture format where their effect can be evaluated and adjusted in real time).

Interestingly, relatively subtle exposure to alternative metaphors may weaken these entrenched concepts. Numerous psycholinguistic studies prime subjects with unexpected metaphoric phrases, give no guidance on interpretation, then find improved comprehension of related discourse and notable shifts from entrenched framing (see, for example, Patterson, 2017). Exposure to comparatively complex metaphoric frames likewise induces shifts away from simplistic points of view (Thibodeau et al., 2016).

So we see that understanding "deliberate metaphor" may not involve anything new that metaphor scholars have not already taken into account. We might therefore wonder if we need any particular name or concept for a "special" type of metaphor, including "deliberate metaphor," in discourse or communication. Perhaps we can perfectly well analyze various aspects of a metaphor's discourse or communicative function in science with what we already know at the level of language and conceptualization as summarized at the beginning of this section. Readers of this volume will find contributions that reveal discourse or communicative functions of metaphors, including science communicators' purposefulness in selecting certain metaphors, but without introducing a new 'type' of metaphor to do so.

After considering the pluses and minuses of 'deliberate metaphor' regarding a metaphor's communicative function we see some value in applying this concept in cases where prime examples of deliberate metaphor occur. However, communicative or discourse functions of metaphor in science conduct and science communication can be analyzed in most cases without invoking this notion and simply using the tools metaphor scholarship already provides, such as distinguishing novel from conventional metaphor, identifying similes and analogies, knowing the scientific knowledge of participants and of a metaphor's general purpose. The various chapters of this volume will illustrate this point.

4. Organization of this volume

It is because of the theoretical and methodological shifts in metaphor studies reviewed here, with the resulting potential to make science more accessible, that we present this volume. We offer overviews of metaphor in broad scientific fields (natural science and social science) and address the functions of metaphor in specific scientific fields for different audiences (cell, marine, and human reproductive biology, thermodynamics, cognitive psychology, criminology).

This volume also includes a study of multi-modal (visual and auditory) aspects of scientific metaphor – a rather neglected aspect in conducting and disseminating science. Taken together the chapters look at how metaphors guide scientific observations, help develop theory and form hypothesis, as well as structuring science pedagogy, all of which will hopefully improve metaphor applications in science. All chapters are prepared not only for metaphor specialists but also with an eye towards practicality that will make this volume valuable to non-linguists, including practicing scientists, historians or philosophers of science, teachers at all levels, and journalists. This leads us to a short summary of chapters, together with the overall organization of this edited volume.

The volume's **first part** provides an overview of the role of metaphor in natural science. First, **Theodore Brown** demonstrates in **Chapter 2** how three overarching social metaphors – the Semiotic Metaphor, Teleology, and Emergence/Supervenience – are used extensively as well as systematically in the study of cellular systems in biology. Operating within the framework of Conceptual Metaphor Theory (CMT), Brown illustrates how the conceptual metaphors BIOLOGICAL PROCESSES ARE COMMUNICATION and CAUSATION IS ACTION TO ACHIEVE A PURPOSE guide scientists from observations to robust theories. Instances of these conceptual metaphors are widely employed when scientists reason about observations, form hypotheses, and generate ideas for new experiments. While the focus of this chapter is on scientists' acquisition and evaluation of new knowledge, Brown also argues that understanding the role of metaphor in these fundamental scientific processes is paramount for teaching science. Furthermore, he points to the value of deliberate metaphor in science pedagogy, for instance, when teachers adapt their explanations to different levels of knowledge on the part of their audience, or when they compare alternative metaphorical models for the same scientific concept.

Whereas Chapter 2 emphasizes the *social* grounding of metaphors in science, **Chapter 3** focuses on embodiment in the sense of scientific metaphors' grounding in our *sensorimotor* experience. **Tamer Amin**'s chapter examines the metaphorical construal of energy in the discourse of physics, thereby complementing Brown's study of metaphor in biology. Chapter 3 also adds another perspective on the concept of metaphor itself, as Amin analyzes the metaphorical construal of energy from the perspective of both CMT and Blending Theory (Fauconnier, 1996; Fauconnier & Turner, 2002). Amin brings together various studies in pedagogical settings, such as science lectures and science textbooks to illustrate the pervasiveness of metaphors used by experts. He also devotes his overview of metaphor in these genres to the students' understanding of energy. This allows Amin to draw conclusions about difficulties faced by learners in natural science education.

The **second part** of this volume complements the foregoing by considering metaphor use in the popularization of science. Concentrating on central concepts in biology and biochemistry, a more complete picture of the role of metaphor in science emerges. In **Chapter 4**, **Bettina Bock von Wülfingen** investigates how metaphors are used in German quality print media on reproductive technologies. Controversial discussion in German public discourse about the use of biotechnology in reproduction was initiated by the birth of the cloned sheep Dolly in 1997. The newspaper articles that Bock von Wülfingen collected for her corpus were published around the year 2000 when the discussion in Germany appeared to become more open to genetic technologies due to a change in political leadership. The then new German chancellor promoted Germany as an ideal location for biotechnology industries, signaling a more liberal and progressive stance towards new reproductive and genetic technologies. Bock von Wülfingen's linguistic data enables her to uncover how metaphors not only *educate* the public but also create future visions in order to *convince* the public, across the political spectrum, of the value of reproductive and genetic technologies. This chapter shows how metaphor can be used to change popular attitudes about a scientific topic in such a way as to persuade the public of its benefits.

In a similar vein, **Chapter 5** explores metaphors in press popularizations for the scientific concept apoptosis. **Julia Williams Camus** also critically examines the metaphors used in the newspaper articles of her corpus. The metaphors used are crucial for the public's understanding of apoptosis and its relation to cancer. However, unlike the preceding chapters whose metaphor analyses mainly focus on the conceptual function, Williams Camus draws attention to the linguistic realizations of metaphor. She applied the Metaphor Identification Procedure, MIP, (Pragglejaz Group, 2007) to her corpora of Spanish and English newspaper articles, which facilitates a detailed analysis of the metaphors' basic senses and mappings. She points out problematic representations of apoptosis that a combination of metaphors create in the media. Possible effects on the public's understanding are further examined by contrasting them with metaphors for apoptosis in specialized genres. Moreover, Williams Camus' comparison of Spanish and English newspapers points to differences and similarities in metaphors for apoptosis between the two languages. Chapter 5 ends with practical recommendations for science popularizers in order to help them avoid unintended and problematic representations.

Chapter 6 adds another important layer in investigating metaphor in science popularization: multimodal analysis. **José Manuel Ureña Gómez-Moreno** integrates verbal and nonverbal metaphor analysis for biological processes. While Ureña Gómez-Moreno's corpus includes both specialized and popular genres, the main part of Chapter 6 considers the popularization of biological concepts in the form of video clips from documentaries. The analysis of video clips accounts for textual, visual, and auditory (including sound/music) elements. In his analyses, Ureña Gómez-Moreno demonstrates how these different aspects of underlying metaphorical thought interact with one another. While some pictorial metaphors, for instance, are conventional and theory-constitutive, a number of multimodal metaphors are used deliberately for other discourse functions in science popularization, in particular for promotional ones in order to attract the audience. It is argued that in science popularization, these two functions can complement each other so that explanations of abstract concepts are delivered in an amusing and striking manner for the benefit of the nonprofessional audience.

The edited volume's **third part** accounts for metaphors in the social sciences and the humanities. Analogous to Chapter 2 on important conceptual metaphors in natural science, **Chapter 7** provides an overview of three influential conceptual metaphors in social science. **Thomas Smith** analyzes the conceptual metaphors SOCIAL PROCESS IS DATASET, SOCIAL PROCESS IS FIELD OF FORCES, and SOCIAL ENCOUNTER IS ADAPTIVE DYNAMICAL SYSTEM, along with their respective submappings, revealing a framework of the development of metaphors in social science. Based on his corpus of specialized social science discourse, Smith shows how metaphors first stimulate hypotheses, are then extended to account for results in successive rounds of observation and theory development, tracing the degree to which each metaphor is found useful and retained over the years. Chapter 7 concludes with a practical ‘checklist’ for scientists, science popularizers, and science teachers in which Smith suggests questions derived from his analyses that are meant to better guide research in the social sciences as well as to enrich the understanding of nonprofessional audiences.

Chapter 8 follows the path of a single, but quite complex metaphor in the social sciences/humanities. **Anke Beger** shows how the metaphor THE BRAIN IS A COMPUTER AND THE MIND IS ITS PROGRAM was first established in specialist discourse to theorize about the human mind and brain. This metaphor constitutes a prime example of *deliberate metaphor* (Steen, 2015), which is first used by the philosopher John Searle, and later modified by other philosophers, to convince fellow academics of particular views on the mind. However, the main part of Chapter 8 examines a college professor’s adaptations of the same metaphor in a philosophy lecture. In her discourse-based metaphor analysis, Beger demonstrates the difficulties faced by educators when trying to deconstruct the complexities of such deliberate metaphors in order to communicate different perspectives of philosophers to students. Beger shows that the philosophy professor in her data struggles with this task. This causes changes in the metaphor structure and consequent misrepresentations of the original argument among the philosophers. The analysis raises awareness of possible pitfalls in metaphor use in science pedagogy that educators should strive to avoid.

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