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On the Problem and Promise of Metaphor Use in Science and Science Communication

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The language of science is largely metaphorical. Scientists rely on metaphor and analogy to make sense of scientific phenomena and communicate their findings to each other and to the public. Yet, despite their utility, metaphors can also constrain scientific reasoning, contribute to public misunderstandings, and, at times, inadvertently reinforce stereotypes and messages that undermine the goals of inclusive science. This paper 1) examines the generative potential of metaphors to the advancement of scientific knowledge and science communication, 2) highlights the ways in which outdated metaphors may limit scientific inquiry and contribute to public misunderstandings, and 3) critically analyzes the implications of cryptic social and political messages embedded in common metaphors in the life sciences.

INTRODUCTION

Metaphors are pervasive in the language of science. Scientists regularly engage in analogical reasoning to develop hypotheses and interpret results, and they rely heavily on metaphors to communicate observations and findings (1). In turn, nonexperts make sense of, and contextualize, abstract ideas and new knowledge through the use of metaphors. While indispensable heuristic tools for doing, communicating, and understanding science, metaphors can also impede scientific inquiry, reinforce public misunderstandings, and perpetuate unintended social and political messages (2). For these reasons, it is especially important for scientists, science communicators, and science educators to acknowledge the conceptual, social, and political dimensions of metaphors in science *and* adopt critical perspectives on their use and effects.

The role of metaphor in scientific thought and communication has been widely considered by philosophers, rhetoricians, and science communication and public understanding of science scholars (2–7). Yet it seems that much of the preeminent work on metaphor in science is still unbeknownst to many scientists, who might benefit from the interdisciplinary insights this body of literature has to offer. This paper draws from several notable publications to highlight the importance of metaphors to scientific reasoning and science communication in the hope of sparking broader interest in, and concern for, the implications of metaphors in the life sciences. Following the tradition of critical studies of science (8–11), we open up the language of science to scrutiny and treat metaphors not just as heuristic and rhetorical devices, but also as social and political "messengers" (2) rooted in cultural dynamics and power relations.

The term *metaphor* can be traced to the Greek word *metaphora,* which is derived from *meta* (meaning "over") and *pherein* (meaning "to carry") (12). As I. A. Richards (13) explains, a metaphor is a comparison between two seemingly dissimilar concepts that involves the "carrying over of a word from its normal use to a new use" (p. 221). Metaphors are crucial in the production of knowledge in that they allow us to make concrete connections between abstract concepts and everyday experiences. A growing body of literature also suggests that metaphors shape the mind, structure our experiences, and influence behavior (14–17). Experimental studies reveal that changes in the framing of policy-relevant issues (such as crime, natural disasters, and climate change) through metaphors can subtly, and covertly, influence the perception of risk, the sense of urgency, and the level of support for proposed "solutions" by acting on pre-existing cognitive schemas and prompting affective responses (15, 18–20).

Lakoff and Johnson's (14) theory of conceptual metaphor posits that the nature of human cognition is metaphorical, and that all knowledge emerges as a result of embodied physical and social experiences. Under this view, metaphors are not mere linguistic embellishments. Rather, they are foundations for thought processes and conceptual understandings that function to map meaning from one knowledge and/or perceptual domain to another. When attempting to make sense of abstract, intangible phenomena, we draw from embodied experiences and look to concrete entities

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to serve as cognitive representatives. For example, in the classic trope, "time is money," our understanding of money, as well as meanings we ascribe to it, are mapped onto a target domain—time. The choice of money as a source domain here is influenced by perceived attribute similarities between it and the target domain concept (time). Subsequently, this linkage between money and time structures our experience with time, in that we conceptualize it as a form of currency that can be spent, invested, valued, and/or wasted (14).

Embodied cognition perspectives shed light on the imperative of metaphor in scientific thought and communication. Conceptual frameworks and theoretical models in science are rooted in the same embodied understandings of the world as those unconsciously employed in other day-to-day physical and social interactions (6). Scientific reasoning, then, is situated in what Gerhard Vollmer (21) refers to as the mesocosm, or the "section of the real world we cope with in perceiving and acting, sensually and motorically" (p. 89). Building on Vollmer's work (as well as Lakoff and Johnson's conceptual metaphor theory), Niebert and Gropengießer (17) argue that, because the human perceptual system is not well suited to interpreting macrocosmic (e.g., the biosphere, solar systems, galaxies) and microcosmic (e.g., cells, molecules, atoms) phenomena, scientists regularly turn to metaphors, grounded in mesocosmic experiences, to make sense of observations and communicate ideas. They explain:

> *Consider the following constructs where scientists make use of everyday experience to explain their theories. Robert Hooke was the first to denote the cell using the term "cell" when an image of a piece of cork under his microscope reminded him of the small rooms, or cells, occupied by monks in monasteries. Kepler developed his concept of planetary motion by comparison with a clock. Huygens used water waves to theorise that light is wavelike. Arrhenius described the greenhouse effect by referring to his experience with hot pots. In ever new variations, scientists employ experiences from everyday life to understand scientific phenomena.* (17, p. 2)

Though the use of metaphorical language in science has been historically criticized by some philosophers of science and scientists on the grounds that metaphors are figurative, ambiguous, and imprecise, their generative potential cannot be ignored. It is, in fact, metaphor that makes theory possible, and a great number of scientific revolutions have been initiated through novel comparisons between natural phenomena and everyday experiences (3).

Limitations of metaphors in science communication

Metaphors in biology and ecology are so ubiquitous that we have to some extent become blind to their existence. We are inundated with metaphorical language, such as genetic "blueprints," ecological "footprints," "invasive" species, "agents" of infectious disease, "superbugs," "food chains," "missing links," and so on. While we may not be able to conceptualize, or communicate, abstract scientific phenomena without employing such metaphors, we must also recognize their limitations, as well as their potential to constrain interpretations of natural processes. In many ways, the metaphors we rely upon may uphold and reinforce outdated scientific paradigms, contributing to public misunderstandings about complex scientific issues.

Take for example the concept of genes as "blueprints," which has guided research in molecular biology for decades (for recent examples of blueprint metaphors in molecular biology publications, see 22–24). Critics argue that conceptualizing the genome as a blueprint (or variations such as codes or instructions) is deterministic, oversimplifies complex gene-gene and gene-environment interactions (10, 25), and is, in many ways, incompatible with recent advancements in the fields of developmental biology and epigenetics (26). If genes really *do* function as blueprints, we should expect a one-to-one correspondence between particular genetic "instructions" and phenotypic outcomes in organisms, with limited input from the environment in structuring variation between individuals. Yet this is not the case. Often, single genes can, and do, direct multiple phenotypic outcomes through epigenetic processes that are responsive to the environment. This concept of variable phenotypic responses to environmental conditions, or *plasticity,* has become an increasingly important framework for understanding not only how organisms develop, but also the role of genes in initiating evolutionary change. Our metaphors, however, have not kept up with recent advances in scientific understandings. Accordingly, this has led some biologists to reject the blueprint metaphor and offer up new ways of conceptualizing the nature of genes (26).

Barbara Katz Rothman (25) suggests that envisioning genes as "recipes" is more accurate in that it allows for the incorporation of time, growth and development, and the importance of the environment on the "final product." She writes,

> *A recipe might make more sense as an analogy. Take bread baking, which combines making something with growth, the growth of the yeast that gives bread its rise. The same recipe under different circumstances gives you different breads. Use a flour from a wheat grown in one part of the country and you have a different mineral composition than that from flour grown somewhere else. Bake on a humid day and you get a heavier bread than you would on a dry day. Bake on a hot day and it rises faster and has bigger airholes. Bake the same recipe every day for a week, and no two loaves will be exactly the same: the web, that distinctive pattern of holes, will vary from loaf to loaf. Bake it in different pans or in different ovens and you'll have differently textured crusts.* (25, p. 33)

While the recipe metaphor is useful in that it provides new ways of envisioning gene-environment interactions, it is not without problems. Some critics point out that it differs little from that of the blueprint metaphor, other than appealing to different personal experiences and triggering different gendered associations (27). Moreover, both recipes and blueprints are essentially a static "set of directions for producing a tangible material product" (28 p. 33) and may be equally constraining when it comes to conceptualizing what genes are and what they do. Survey, interview, and focus-group data collected by Condit *et al.* (27) indicate that genetic metaphors activate diverse, context-dependent meanings (as well as varying degrees of deterministic connotations) amongst different audiences, and they highlight the need for more empirically-grounded research in critical discussions of metaphor use in the life sciences.

Metaphors as sociopolitical messengers

In the United States, many of the metaphors we use to talk about topics in biology and ecology are competitive and militaristic (e.g., evolutionary "arms-races," cells being "hijacked" by viruses), and/or technology driven (e.g., the brain as "computer," body as "machine," cells as "factories"). Our choice of words not only reflects deep cultural cosmologies and historical influences (2) but also reinforces cultural norms, ideologies, and beliefs. Though metaphors are indispensable tools for communicating science, they are sometimes misleading to the general public and can be easily exploited in attempts to further social and political agendas (26).

Since the 17th century, mechanical metaphors have been used extensively by scientists to make sense of nature (26). Part of the appeal of the machine-based analogies that emerged during the Scientific Revolution resided in their perceived compatibility with religious beliefs. As Pigliucci and Boundry explain, "the mechanical pictures of living organisms and the cosmos at large converged into an intellectual tradition where theology and science were intimately intertwined" (26, p. 455). Machine metaphors allowed for religious speculation and inferred an inescapable conclusion: that a designer or creator must exist (for all machines have a maker). Though the vast majority of working scientists today reject design as an explanation for scientific processes, they nonetheless still rely on mechanical metaphors to understand (and communicate) the natural world. As a result, science education is rife with machine-based explanations and imagery that may inadvertently foster teleological thinking in students and the public. The intelligent design movement has exploited scientists' use of machine metaphors and continues to employ machine analogies as powerful persuasive tools (26).

The "war on invasive species" is another example that demonstrates how certain sociopolitical ideologies become entangled with scientific discourse. Militaristic metaphors are abundant not just in popular articles on invasive species, but also in the scientific literature (2). Despite debates over what constitutes an invasive vs. a native species (as well as disagreements over whether or not species that spread rapidly are any more damaging than species with limited ranges), the language of invasion biology incites fear and encourages action. Invasion metaphors are performative in the sense that they encourage "weed pulls and control programs, the erection of barrier zones, lucrative contracts for herbicide companies, and research grants for invasion biologists" (2, p. 175). Such metaphors also blur "facts" with "values," reflecting—and reinforcing—nationalistic concerns regarding invasion and immigration, xenophobia, and commitment to militaristic responses (2, 29).

Popular metaphors in biology and ecology are also windows into a culture of science that is deeply rooted in hegemonic norms and values that are perpetuated through both the process of scientific inquiry and science communication (30, 31). When metaphor choices are not appropriately vetted with careful social, political, and historical considerations in mind, they may subtly contribute to the alienation of individuals and groups. Joan Herbers' criticism of entomologists' use of slavery metaphors (31) to describe the behavior of ants illuminates this issue. Herbers explains that, though unintentional, the use of such "racially loaded" (p. 104) metaphors in contemporary scientific discourse functions to naturalize human social institutions and unequal social relations, and is potentially offensive to the many descendants of slaves living in the United States and other parts of the world today (31). Descriptions of "slave-making" ants originated during the height of the slave trade of the 1800s and, despite being a misleading and inaccurate description of actual ant behavior, continue to be used in popular publications and journal articles (a recent library search by the authors using ex libris primo identified 44 scholarly articles published between 2012 and 2017 that made reference to slave-making ants). Equally as problematic is the persistent use of other anthropomorphic analogies (harems, castes, colonies, etc.) in the life sciences to describe non-human social relations. Such analogies inadvertently legitimize systems of dominance and hierarchy, reproduce racial and gendered stereotypes, and may perpetuate dehumanizing colonial representations of historically subjugated groups (32).

Remnants of colonialism also echo within scientific discourses through the use of metaphors that equate the practice of science itself with penetrating the unknown, conquering nature, and pioneering new frontiers (30, 33). Many science-related metaphors harbor traditionally masculine values and may activate implicit associations between science, gender, and/or race, thus reinforcing dominant stereotypes about *who* does science. This is especially worrisome given that recent studies involving primary, secondary, and undergraduate students indicate that stereotypes of scientists as "white" and "male" continue to persist and negatively impact the science aspirations of students from underrepresented groups (34–36).

In light of these observations, some scholars have attempted to generate new metaphors that are more inclusive and less alienating to individuals whose identities and experiences do not align with perceptions of the culture of science. Flannery (30), for example, offers "quilting" as an alternative metaphor for scientific research that directs attention to similarities in the skills and processes employed by both scientists and artisans (creativity, collaboration, painstaking attention to detail, the cultivation of tacit knowledge, etc.). She argues that if the metaphors we used to talk about science acknowledged the communal, craft-like aspects of scientific endeavors, we might imagine the process of science in productive new ways that are less alienating to traditionally marginalized groups. Like all metaphors, however, Flannery's is not without problems and limitations. Some readers will undoubtedly object to this metaphor on the grounds that it is exclusionary in its own right (to individuals and groups who are unfamiliar with, and/or uninterested in, quilt-making traditions), and that it obscures the important fact that the final outcomes of scientific research are unknown (as opposed to the predetermined products of quilting). Nevertheless, Flannery's considerations provide opportunities to envision how novel metaphors might emphasize different ways of *doing* science and broaden (or narrow) its appeal to underrepresented groups. Much more research is still needed in examining the role of science-related metaphors in activating stereotypical representations of how science is done, and by whom.

CONCLUSIONS AND FUTURE DIRECTIONS

For all of their problems, metaphors are indispensable tools for both practicing and communicating science. No metaphor is perfect, and incongruities between target and source meanings are unavoidable. Some metaphors, however, may be more (or less) constraining when it comes to conceptualizing complex scientific issues. Careful consideration must be paid not only to the ways in which metaphors may contribute to public misunderstanding, but also to how their use may unintentionally reinforce particular social and political messages that undermine the goals of inclusive science. More interdisciplinary collaborations between scholars in the life sciences, social sciences, and the humanities might be helpful in cultivating new metaphors that better align with contemporary values and goals of the scientific community at large and are more salient, more familiar, and less offensive to underrepresented groups. Additionally, more attention could be paid to helping students develop the skills and competencies needed for identifying metaphors, assessing their strengths and limitations in conceptualizing abstract ideas, and unpacking their more subtle social and political messages. We suspect that educational activities involving the dissection of metaphors in the science classroom might help move students toward deeper understandings of scientific concepts and help foster greater concern for, and commitment to, civic responsibilities among future scientists.

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