Metaphors as tools for understanding in science communication among experts and to the public

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Science communication is highly important in present-day society. But mere factual information transfer does not suffice for enhancing public understanding of scientific results, theories, and concepts. In this paper we compare science communication among experts with communication from experts to laypeople, to better understand the role of metaphors in constructing understanding of abstract scientific concepts. As a case study, we analyze specialist and non-specialist scientific articles on epigenetics, the study of heritable changes in gene expression not altering DNA sequence. The results of our analysis show that there is no substantial difference between the two types of articles in frequency of metaphors and in their content. However, the function of the metaphors is different: the figurative aspect of metaphors is employed for public understanding but plays no role in specialist scientific articles. We outline the implications of these results for current philosophical debates on scientific understanding and public understanding of science: (1) metaphors are tools for rendering theoretical concepts intelligible, for both expert and lay audiences; (2) expert and public understanding differ in degree rather than in kind; (3) conveying understanding crucially involves skills: metaphors in this context do not so much add knowledge as enhance relevant conceptual reasoning abilities.

Keywords: Science communication, scientific understanding, metaphor analysis, epigenetic

1. Introduction

Explaining scientific concepts, theories and results to a lay audience is crucial in present-day society; witness the recent context of medical and governmental decision-making and policy creation around Covid-19. However, it can be a real

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challenge to make abstract scientific concepts and complicated mechanisms intelligible to laypeople. For a long time, it was assumed that the gap between expert and lay understanding of science was due to a knowledge deficit on the side of the general public: by simply providing more, or more detailed, information about science, the general public's so-called 'scientific literacy' would improve, or so it was believed (see Miller, 2001). Attempts to enhance scientific literacy based on this 'deficit model' failed, however, and this inspired the development of alternative, more sophisticated models of public understanding (Brossard & Lewenstein, 2009; Reincke et al., 2020). Consensus about which model is best has not yet been reached, however.

We submit that recent developments in the philosophy of science may help to answer questions that are fundamental here: What exactly is scientific understanding and how can it be achieved? In recent years, philosophers of science and epistemologists have investigated the nature of (scientific) understanding (see Grimm et al., 2017, for an overview). Relevant issues are, in particular, whether expert and lay understanding differ only in the *degree* of knowledge or also in the *kind* of knowledge involved, and moreover, whether understanding is simply a particular type of knowledge or involves something essentially different, for example certain abilities or skills. Once we have answered these questions, we will be ready to examine whether non-experts can also possess such scientific understanding and, if so, how and to what extent. It seems clear–both from the failure of the deficit model, noted above, and from debates in philosophy of science–that understanding amounts to more than merely factual knowledge, even though there is currently no consensus on exactly what scientific understanding consists in and when it is achieved.

Our paper addresses these issues via a case study of the use of metaphors in specialist and non-specialist scientific articles. We focus on metaphor use because of the abundant research suggesting that metaphor analysis is a fruitful method for gaining insight into the nature of understanding, particularly in abstract domains where metaphors can provide a model of how an abstract concept can be understood (e.g., Gibbs, 1996; Pecher et al., 2011; Yob, 2003; though see Vervaeke & Kennedy, 2004, among others, for qualifications). Analyzing metaphors can, accordingly, provide insight into the way the writer or speaker understands a phenomenon, as well as into the way understanding of abstract concepts is constructed in the reader or hearer (Cameron & Maslen, 2010). To achieve such insight, we have investigated and analyzed differences and similarities in metaphor use in publications for expert and lay readers on the topic of epigenetics. This analysis can provide insight into the extent that the construction of understanding of epigenetics in experts and laypeople is based on similar conceptual models.

2. Theoretical Framework

2.1 Expert versus public understanding of science: A philosophical analysis

Currently, philosophy of science is witnessing a debate about the nature of scientific understanding.[1] It is widely acknowledged that scientists strive to explain phenomena and that successful explanations provide understanding, but, as said, there is no consensus on what exactly scientific understanding consists of and when it is achieved. A central issue in the current philosophical debate on scientific understanding is the apparent opposition between two rival conceptions of understanding: understanding as a skill (ability) and understanding as a species of knowledge.[2] According to some, understanding is merely a species of knowledge. This understanding-as-knowledge view is defended by Khalifa (2017); Lipton (2004), and Strevens (2013), and is implicit in many traditional approaches in epistemology and philosophy of science. According to others, understanding transcends knowledge: it requires abilities. The understanding-as-skill view has been developed and defended by De Regt (2017) and Wilkenfeld (2013).

Advocates of the understanding-as-knowledge view claim that scientific explanations provide us with a specific kind of knowledge, which constitutes understanding. Thus, Lipton (2004, p. 30) writes: "Understanding is not some sort of super-knowledge, but simply more knowledge: knowledge of causes." If we know, for example, that the global temperature has risen in the past century, we have knowledge of global warming; and if we know, in addition, that the cause of this global warming is the increase of CO_2 in the atmosphere in combination with the greenhouse effect, we have understanding of the phenomenon of global warming. Although this might seem a plausible view at first sight, it becomes clear quite quickly that mere *knowledge* of causes is insufficient for understanding. It is one thing to *know* that the greenhouse effect causes global warming, but it is quite another to *understand* why or how it does so. A student may be able to answer the question 'Why does global warming happen?' correctly by answering 'Because of the greenhouse effect'. But this does not imply that she understands why global warming happens – she merely knows what people claim as its cause. However, the student does understand why global warming happens if she has the ability (the skill) to apply this knowledge, to see what its consequences are in specific cases (De Regt, 2017, pp. 24–29).

1. For overviews and recent contributions, see De Regt (2017), De Regt et al. (2009), Grimm et al. (2017), and Khalifa (2017).

2. To be sure, skill can also be regarded as a form of knowledge (know-how), but here we focus on the standard view of knowledge as propositional (e.g. know-that).

On the basis of this idea, De Regt (2017) has developed a contextual theory of scientific understanding, which we will use as a starting point for our investigation of differences and similarities between expert and public understanding of science. The core idea of this theory is the notion of intelligibility, which is defined as the value that scientists attribute to the cluster of qualities that facilitate the use of a theory (De Regt, 2017). Intelligibility is not an intrinsic, but a contextual value: a scientific theory is intelligible to scientists if their skills are attuned to its qualities. The production of scientific knowledge and explanations necessarily involves skills, which entails that scientific theories should be intelligible to their users. Accordingly, intelligibility is essential for achieving the epistemic aims of science. However, since it is a contextual value that depends in part on scientists' skills, judgments of whether a theory is intelligible may change with the context: scientists in different historical or disciplinary contexts may assess a theory's intelligibility differently.

Whether or not theories are regarded as intelligible depends on scientists' skills and the available tools and is therefore partly a matter of familiarity: only if a tool is familiar to scientists, and if they have developed the relevant skills, can it be used for the purpose of constructing explanations that provide understanding of a phenomenon. This familiarity is typically acquired in scientific practice and in education; it does not have to come from everyday experience (see De Regt, 2017). As we will see below, laypeople–who lack relevant scientific education and experience–will often need to borrow alternative tools for understanding from domains with which they are familiar, such as everyday life. For example, those who are familiar with the mechanism of a greenhouse can use this as a model for understanding the causes of global warming.

The contextual theory of scientific understanding describes the understanding of expert scientists, who develop new models and explanations for particular phenomena on the basis of theories that are intelligible to them. Accordingly, scientific understanding requires expert skills to advance the state of the art in their field. It is, in other words, understanding of a highly specialized nature, requiring highly specialized skills. Clearly, the general public does not and cannot be expected to acquire these skills (e.g. advanced mathematical and experimental skills), at least not to the same degree as the expert scientists. Note that the failure of the traditional deficit model of public understanding is a prima facie argument in favor of conceiving of understanding in terms of skills rather than knowledge. Merely supplying laypeople with more knowledge does not automatically increase their understanding of a scientific domain.

This prompts the question of whether the construction of scientific understanding is accessible to non-experts at all. As a first step toward answering this question, providing an indication of what the differences between the construction of expert and public understanding of science may involve, we have carried out an empirical study that aimed to investigate similarities and differences between the ways in which scientific understanding is conveyed through metaphor to expert scientists and to the general public. Indeed, there is an extensive body of linguistic research that focuses on how metaphor use may contribute to understanding, which we will briefly review in the next subsection.

2.2 A linguistic perspective on the role of metaphor in understanding

A large body of linguistic evidence suggests that metaphors play a significant role in obtaining and conveying understanding. They are especially important for communicating abstract concepts and reasoning with them, in science, psychology and elsewhere (Beger, 2015; Duit, 1991). Metaphors can help us to apprehend a new or abstract concept by representing it in terms that are familiar to the reader or hearer and can thereby enhance the intelligibility of the concept (Gee, 1978; Lakoff & Johnson, 1980; Miller, 1979).

The use of metaphors for modelling new concepts proves to be of great value for conveying understanding of them. For example, entrepreneurs are known to employ metaphors when explaining abstract ideas and uncertainties of their proposed venture in the communication to employees and (prospective) investors (Cornelissen et al., 2012). There is a comparable role for metaphors in science education, where metaphors are used to acquire and convey understanding of phenomena. Think, for example, of fluid models of energy and electricity, which are widely held to provide understanding despite their metaphorical nature. Many people think of electricity as a fluid-like substance that is carried through electrical wires in much the same way that water is pushed through pipes. While this fluid model would lead to incorrect conclusions in some circumstances, it is highly effective when thinking and reasoning about simple problems of electrical circuitry (Gentner & Gentner, 1983). Similarly, in non-specialist articles on cancer, metaphors act as cognitive devices that help to structure scientific knowledge by organizing the narrative into a coherent discourse (Williams Camus, 2009).

According to Knudsen (2003), scientific metaphors enable the construction of a mental model of an abstract scientific theory, which provides the basis on which new hypotheses, ideas and theories can be built. She illustrates her theory using the example of the metaphor 'genes as a code' proposed by Schrödinger in his famous book *What is Life* (1944). Schrödinger described the structure of chromosome fibres as a code-script, suggesting that by 'breaking the code' the creation of life could be revealed. The initial 'genes as a code' metaphor turned out to be extremely influential to our understanding of protein synthesis and enabled the generation of new hypotheses on linked biological processes.[3] The process of protein synthesis from DNA is, for example, called 'translation' in which the 'genetic code' is to be translated. The metaphor 'genes as a code' thus functions as a *structural metaphor* (in the sense of Lakoff & Johnson, 1980, Chapter 13) for explaining genetics. When metaphorical terms are first introduced in the scientific community, the understanding of the abstract concepts is facilitated through the figurative aspect of metaphors. Knudsen refers to metaphors in this stage as 'open', because they still need to be explained. Since metaphorical conceptual models, such as genes as a code, make certain aspects of the explained phenomenon more salient than others, they also shape the understanding of the phenomenon rather than being mere 'objective' tools to create understanding.

As Knudsen also points out, however, many metaphorical terms in specialist scientific articles on genetics lose their figurative function once they have become accepted within the scientific field and become part of the expert scientific vocabulary. At this stage, as metaphors become conventionalized, the metaphorical term can be used without further explanation or reference to its basic meaning and will often refer directly to a specific substance or process (cf. English, 1998). For example, 'translation' directly refers to a cellular process in genetics that all experts in the field are familiar with. Knudsen refers to these metaphors as being 'closed'. This is similar to what Goatly (1997), Johnson-Sheehan (1998), and others refer to as 'dead' metaphors, and is in line with what Bowdle and Gentner (2005) call "the career of metaphor".

When metaphorical terms, such as 'translation', are explained to non-experts, their figurative aspect may again become useful for making their abstract content intelligible. Metaphors that in expert scientific articles are used in a closed sense may therefore regain their figurative aspect in popular scientific articles. This process is described by Knudsen as the 're-opening' of metaphors (2003, 1255). Similarly, Richards (1936) describes 'waking up' dead metaphors; Goatly (1997) writes about 'inactive' versus 'revitalized' metaphors; Kyratzis (1997) about metaphors being 'frozen' versus 'fresh'; and Müller (2008) again uses the contrast between metaphors being 'sleeping' versus 'awake'.[4] Clearly, though, this

3. Even though Schrödinger identified the relevant chemical substance incorrectly (Knudsen, 2003, p. 1251).

4. The Deliberate Metaphor Theory of Steen (2015) differs, in our view, from Knudsen's metaphor theory. Knudsen distinguishes three uses of metaphors within a 'metaphor trajectory', as explained above, while Steen primarily distinguishes two uses of metaphor: those that are used deliberately as a metaphor and those that are not. The 'metaphor trajectory' of Knudsen fits better into the contextual theory of scientific understanding because it is linked to the development of scientific understanding.

'metaphor trajectory' is not (always) unidirectional; metaphors used in scientific jargon may also find their origin in popular literature.

2.3 Research aim and hypotheses

While metaphor use in specialist scientific articles has been examined extensively (e.g. Hesse, 1963; Schön, 1963), Knudsen's theory, supported by empirical study, is exceptional in that it addresses metaphor use in non-specialist scientific articles. Other work on metaphor use in science communication tends to focus on the appropriateness of the metaphors that are used, rather than on their role in constructing understanding. In the present study, we analyze metaphor use in both expert and lay articles about an abstract scientific subject, i.e. epigenetics. In addition, we reflect on the results in the light of the current debate in philosophy of science regarding the nature of expert and public understanding of science, and the similarities and differences between them.

We have carried out such a comparative analysis by comparing the frequency of metaphor use, identifying structural metaphors in the articles, identifying groupings of vehicle terms of such structural metaphors, and by comparing the function of metaphor in specialist and non-specialist scientific articles. For the latter, we employ a qualitative analysis in order to link the results with Knudsen's theory of open and closed metaphors. Our research questions regarding similarities and differences between expert scientific understanding and public understanding of science are: Does the frequency of metaphor use in specialist literature differ from that in literature for non-specialists? How does the content, rate and function of metaphors in specialist articles compare with that in non-specialist articles? Our working hypotheses are:

- Metaphors used in specialist and non-specialist articles on the same scientific subject will refer to mappings from similar source domains (cf. Knudsen, 2003). This hypothesis will be tested by comparing structural metaphors in both kinds of articles.
- Metaphors have different functions in specialist and non-specialist scientific articles (cf. Knudsen, 2003). The latter contain open metaphors that have a pedagogical function, while metaphors in the former are typically closed and function like any other scientific concept.
- Metaphors can enhance the intelligibility of abstract concepts and theories (cf. Cornelissen et al., 2012; Hill & Levenhagen, 1995). We will examine whether abstract scientific concepts are linked to metaphors with the ostensive pedagogical purpose of improving the intelligibility of the concept for the readers.

3. Methods

As a case study for our comparison, we selected articles on the topic of epigenetics, a scientific field that has attracted the attention of popular-scientific media. In this section we will give a brief sketch of epigenetics and describe our research design (3.1), the method employed (3.2), and data sources (3.3).

3.1 Choice of case and research design

Our chosen case–epigenetics–is a subfield of genetics, which is concerned with changes in gene expression that do not alter the underlying DNA sequence. While it has been argued that the term 'epigenetics' covers many different kinds of mechanisms (Greally, 2018), the articles that we analyzed follow the general hypothesis that epigenetic mechanisms determine which genes will be expressed and which neglected, based on environmental cues, thereby enhancing the adaptiveness of an organism to its environment. For example, in a fetus of a mother who has limited access to food and nutrients during pregnancy, a different set of genes may come to expression, compared with a fetus whose mother has access to plentiful nutritional resources to optimize its metabolism to the future environment. Furthermore, since environmental factors may influence gene expression via epigenetic mechanisms, it is believed that modifying epigenetic factors may provide possibilities to lower one's genetic risk to develop a partly heritable disease. The field of epigenetics has therefore received great attention from researchers and the general public, including research on the appropriateness of metaphor use in the field (Dubois et al., 2019) and the use of epigenetics metaphors in UK broadsheets (Stelmach & Nerlich, 2015).

When C.H. Waddington (1957) introduced the term 'epigenetics', he used a visual metaphor to express his view of biological development: the epigenetic landscape. This metaphor played an important heuristic role in the development of epigenetics (Baedke & Schöttler, 2017), and while today it has become a technical term used by scientists working in this field of study (or, in Knudsen's terms, a closed metaphor), a variety of metaphors is still being used in both scientific and popular-scientific publications to communicate understanding of epigenetics. Therefore, epigenetics appears to be a good topic for a case study to answer our research questions.

We selected articles with the following considerations in mind. First, to control for potential bias in metaphor use by a specific author or publisher, the articles we analyzed were all written by different authors, and only two were published in the same magazine. Second, we have chosen articles that are concerned with the same scientific concept, i.e. epigenetics, because choice of metaphor plausibly depends on the subject (different metaphors will be suited for different concepts or mechanisms). Third, our decision to choose epigenetics as the concept of interest was motivated by the fact that epigenetics describes a mechanism that cannot be observed directly; this thus increases the potential importance of metaphors in order to communicate about it. Finally, the subject of epigenetics has attracted much attention in non-specialist articles, which is clearly not the case for all scientific fields.

It should be noted that metaphor use in the field of epigenetics has been criticized for not conveying accurate understanding of the subject (Dubois et al., 2019; Nerlich et al., 2020; Taylor & Dewsbury, 2018). However, in our study we will only provide a descriptive analysis of metaphor use in the epigenetics literature, and refrain from normative assessment of the metaphors employed. The aim of our paper is not to contribute to the debate about *specific* metaphors in epigenetics, but to use this as a case to investigate the function of metaphors in science communication. Functions that metaphors may have in popular scientific articles other than conveying scientific understanding, such as attracting readers and structuring a text (Williams Camus, 2009), have not been analyzed because they lie outside of the scope of our study.

3.2 Metaphor analysis

To identify verbal metaphoric expressions, we used the method of Cameron and Maslen (2010), adapted from Pragglejaz Group (2007). For example, in the sentence "Epigenetics is about turning genes on or off" (Crossley, 2013), we identified "turning [..] on or off" as a metaphorical expression because its meaning in the article is different from its more basic meaning, but the more basic meaning is used here to explain epigenetics. That is, the more basic meaning of "turning [..] on or off" refers to a switch that is turned on or off, for example a light switch, which allows the reader to understand epigenetics as a mechanism through which a gene is activated or not. Metaphoric expressions were then grouped into categories of structural metaphors. We restricted ourselves to structural metaphors as the ones providing richer source domains for delineating target concepts, as opposed to simpler orientational or ontological metaphors (Lakoff & Johnson, 1980). In metaphorical expressions, vehicle terms represent the source for figurative reasoning about the scientific concepts. These terms were grouped following Cameron et al.'s (2010) method of analyzing systematic metaphors. The first author performed the initial analysis and discussed the results with the two co-authors. Any disagreements concerning the metaphor coding were resolved through discussion. An overview of all the metaphoric expressions identified in each of the articles that were analyzed can be found online (see Smedinga et al., 2023).

3.3 Data sources

We analyzed 12 articles in total: six articles aimed at scientific specialists and six articles aimed at a general audience (non-specialists), each by a different author and all published in high-impact peer-reviewed scientific journals and international popular-scientific magazines that reach out to a wide audience, respectively. We chose to analyze written texts in line with Knudsen's metaphor analysis (2003), which has the added benefit of reaching a relatively wide audience. As there is no strict dichotomy between specialist and non-specialist audiences in practice, we chose types of articles in which it is clear that they either serve an audience with or without background knowledge of biology or epigenetics. For example, the articles aimed at scientific specialists have been published in peer-reviewed scientific journals, while the articles aimed at a general audience were published in (online) magazines or newspapers that have a broad readership, such as *TIME Magazine*. The articles aimed at scientific specialists (average date of publication: 2002) were on average published ten years before the articles aimed at the general audience (average date of publication: 2013). This difference is not expected to influence the results because the mechanisms described in the articles are roughly similar.

The selected articles aimed at scientific specialists were published in journals that aim to communicate research results to an audience of scientists, explaining epigenetics from different perspectives. To ensure that the mechanisms that were explained were comparable across the articles, all of the articles revolve around epigenetics as a phenomenon itself rather than concerning its different parts or processes, which are specialisms in the given research field of epigenetics. Finally, it should be noted that it is the nature of the journal that determines whether the article is generally intended for scientists or for a lay audience; it does not make a difference whether or not authors are experts in epigenetics. The choice of journal is one of the factors that influences metaphor use, but this has a very limited impact on our results as we are not concerned with the details of the individual metaphors–but with metaphor use on a more general level.

Articles aimed at the general public:

- Cloud, J. (2010). Why genes aren't destiny. *TIME Magazine*
- Miller, P. (2012). A thing or two about twins. *National Geographic Magazine*
- Crossley, M. (2013). Explainer: What is epigenetics? *The Conversation*
- Gorski, D. (2013). Epigenetics: It doesn't mean what quacks think it means. *Science Based Magazine*
- Ennis, C. (2014). Epigenetics: A beginner's guide to explaining everything. *The Guardian*
- Park, A. (2015). Explaining 'Epigenetics': The Health buzzword you need to know. *TIME Magazine*

Articles aimed at a specialist audience:

- Laird, P., & Jaenisch, R. (1996). The role of DNA methylation in cancer genetic and epigenetics. *Annual Review of Genetics, 30*, 441–464
- Henikoff, S., & Matzke, M. (1997). Exploring and explaining epigenetic effects. *Trends in Genetics, 13*(8), 293–295
- Baylin, S., & Herman, J. (2000). DNA hypermethylation in tumorigenesis: Epigenetics joins genetics. *Trends in Genetics, 16*(4), 168–174
- Reik, W. et al. (2001). Epigenetic reprogramming in mammalian development. *Science, 293*(5532), 1089–1093
- Goldberg, A. et al. (2007). Epigenetics: A landscape takes shape. *Cell, 128*(4), 635–638
- Turan, N. et al. (2010). Explaining inter-individual variability in phenotype: Is epigenetics up to the challenge? *Epigenetics, 5*(1), 16–19

4. Results

Overall, we observe that the analyzed texts aimed at a specialist audience are more lexically dense, contain more jargon, and are written more cautiously, which can be expected for academic articles (see Hyland, 2005). The texts aimed at a general audience are more illustrative, in terms of examples and images used, are lighter to read, and are more likely to touch upon the meaning of epigenetics in daily life, which is in line with previous analysis of popular science articles (see Miller, 1998).

4.1 Quantitative results

Figure 1 illustrates the 12 structural metaphors that, taken together, were employed most in the articles analyzed. The number of metaphoric expressions found in each article, the metaphor ratios and an explanation of the figurative meaning of the structural metaphor vehicle terms can be found online (see Smedinga et al., 2023). The metaphor ratio is determined by dividing the total number of metaphoric expressions in the article by the total word count.

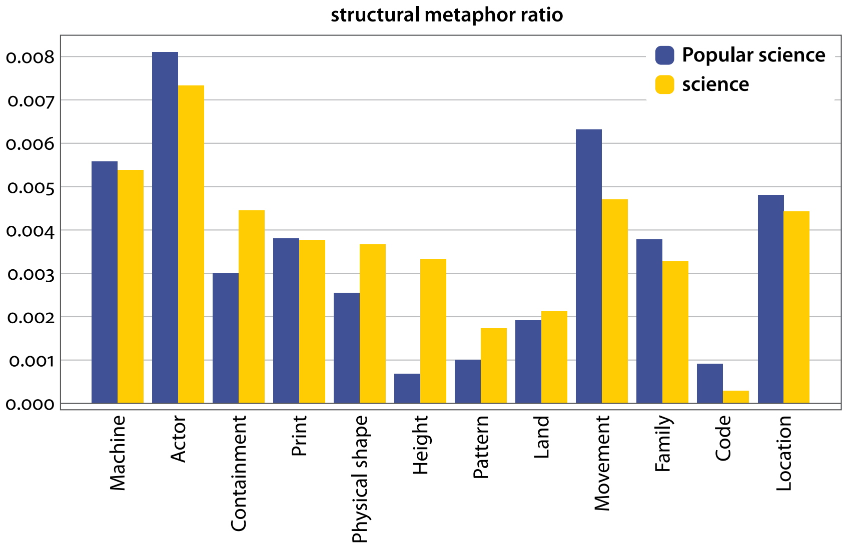

Figure 1. Occurrence of structural metaphors per conceptual domain in the specialist (left) and non-specialist (right) scientific articles

The results show no significant difference between the mean ratios of use of the structural metaphors in specialist and in non-specialist scientific articles (Figure 2) nor between the number of times each of the structural metaphors was employed in the two types of articles (Figure 1), with the exception of the outlier of the 'height' structural metaphor ($p = 0.0036$, unpaired t-test). This difference is due to an exceptionally frequent use of the structural metaphor of height in the scientific specialist article written by Turan, Katari, and Coutifaris (22 metaphors in 2043 words). This difference can be explained by the metaphorical use of the terms 'transcript level' and 'mRNA level' in the cell, in which 'level' was labelled as referring to the 'height' structural metaphor.

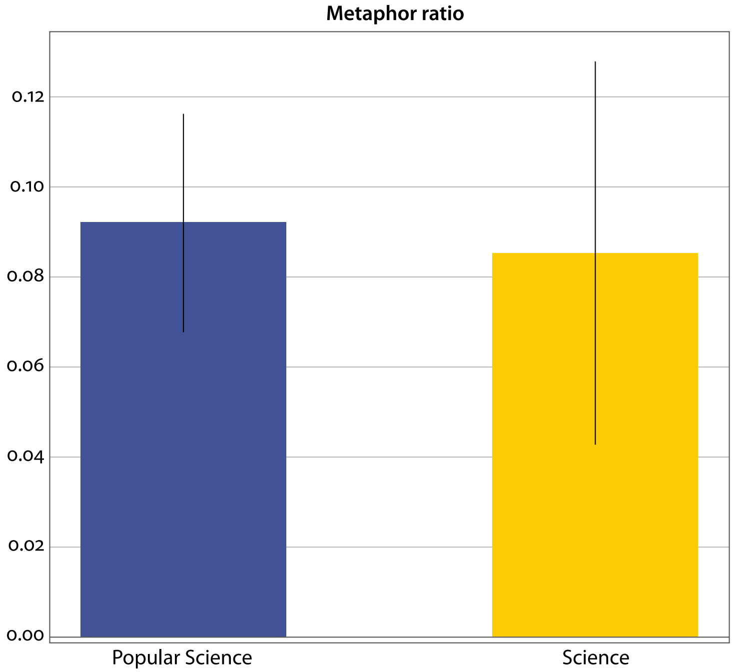

Figure 2. Means and standard deviations of metaphor ratio in the specialist (left) and non-specialist (right) scientific articles

4.2 Qualitative results

The quantitative results above show no difference in the *frequency* of use and content of the structural metaphors employed in expert and lay scientific articles on epigenetics. Stelmach and Nerlich (2015) showed that in UK broadsheet articles about epigenetics, it was not entirely clear what target domains were being referred to with the metaphors that were used, which was believed to reflect struggles about what epigenetics involves. Complementary to those findings, we observed, a different *function* of the metaphors in the different sets of articles that were analyzed. In the expert scientific articles, metaphors generally referred to specific mechanisms or substances that were assumed to be familiar to the reader, such as a 'CpG island' referring to a part of the DNA. Hence, metaphors are used as any other, non-metaphorical, concept.

In non-specialist scientific articles, by contrast, metaphors played a central role in the explanation of abstract concepts by explaining such a new concept in terms of a familiar one. For instance, the biological process of methylation–fundamental to epigenetics–is explained in one of the non-specialist scientific articles as follows: "so methylation is like a blue highlighter telling the cell 'you don't need to know about this section right now'" (Ennis, 2014). In the specialist scientific articles, it is presumed that the reader is already familiar with the concept of 'methylation'. This observation is in line with Knudsen's theory of metaphor function, discussed in Section 2.2 above, suggesting that metaphors in specialist scientific articles are closed, as opposed to being open in non-specialist articles. In the next subsections, the difference in function of metaphors in the articles will be elucidated with examples of closed and open metaphor use from the articles we analyzed.

4.3 Open metaphors in non-specialist scientific articles

We found that metaphors in scientific articles for laypeople are typically used for explanatory and illustrative purposes, in contrast to metaphor use in the specialist scientific articles. Metaphors in the non-specialist articles generally contribute to improving the intelligibility of a new (scientific) concept by explaining it in terms of a familiar one. If the link between the metaphor and the new concept is explained, the source domain serves as a model for the explained concept. The quote below from *TIME Magazine*, an article aimed at the general public, illustrates this:

> "These <u>patterns</u> of gene <u>expression</u> are <u>governed</u> by the cellular material – the epigenome – that <u>sits on top</u> of the genome, just <u>outside</u> it (hence the prefix epi-, which means above). It is these epigenetic "<u>marks</u>" that <u>tell</u> your genes <u>to switch on or off</u>, to <u>speak loudly or whisper</u>."
> (Cloud, 2010, p. 50; vehicle terms underlined here and in the later examples)

First, *marks* in *epigenetic <u>marks</u> that tell your genes to switch on or off* can be identified as a metaphor because the meaning of the term in this context differs from its more basic meaning: "a printed or written symbol that is not a letter or a number" (Macmillan online dictionary, 2007). The cross-domain mapping that is offered represents the following model of epigenetics: 'the process of epigenetics is like marking genes'. Once this model of epigenetics has been made intelligible to the reader, new aspects of epigenetics can be linked to it. The article quoted above continues to refer to the structural metaphor of 'epigenetic marks', for example as follows:

> It is through epigenetic <u>marks</u> that environmental factors like diet, stress and prenatal nutrition can make an <u>imprint</u> on genes that is <u>passed from</u> one generation <u>to</u> the next. (Cloud, 2010, p. 50)

To *make an imprint on genes* in the quote above is linked to the structural metaphor of 'the process of epigenetics is like marking genes' because the "imprint" metaphor refers to its more basic meaning: "to leave a mark on a surface by pressing an object onto it" (Macmillan online dictionary, 2007). Though this specific metaphor has not been explained in the article, it can still be marked as open according to the theory of Knudsen because it is linked to a structural metaphor that has been explained (Knudsen, 2003). This also explains why *mark*s is highlighted, by the use of quotes, as a metaphor by the author (one of many possible co-textual means of signaling metaphor use, as Goatly (1997, Chapter 6) explains.

The widespread use of metaphors in popular-scientific articles, and the open way in which they are used, show that it is more than just knowledge of facts that is shared with the lay reader. These texts aim to improve *understanding* as described in Section 2.1: the ability to apply the information, to reason with it, and to see what its consequences are in concrete situations. The texts provide the reader with a mental model of the mechanism of epigenetics (a process similar to marking genes that should not be expressed), which they can use to reason about the mechanism and its implications. In this sense the metaphors are the tools that render the theory of epigenetics intelligible to the lay audience.

4.4 Closed metaphors in specialist scientific articles

The metaphors found in the specialist scientific articles can be characterized as predominantly closed in the sense that they directly refer to, for example, substances or processes presumed to be familiar to the reader. Accordingly, the metaphorical term is used in the same way as any other, non-metaphorical term and has thereby lost its figurative origin. This role of metaphor in specialist scientific articles can be illustrated by the following quote:

> <u>Reprogramming</u> in germ cells is needed for the <u>resetting</u> of <u>imprints</u>. Whether it only occurs in species with <u>imprinting</u> is not known, because no comparative data are available for other vertebrates (such as amphibians or birds) in which <u>imprinting</u> is <u>absent.</u> (Reik et al., 2001, p. 1090)

In the context of this article, the meaning of "imprint" differs from its more basic meaning, as previously discussed. Since the metaphor is not explained in this article, and neither contributes to an explanation of a concept, it can be marked as closed. The reader is thus expected to know what "imprint" means in this context, which suggests that the metaphor is conventionalized in this field of science. The fact that the first author of the article is based at a laboratory called the Laboratory of Developmental Genetics and Imprinting, supports this hypothesis. Metaphorical expressions similar to the ones we characterized as closed have been characterized by Giles as 'dead metaphors' in scientific articles on the cloned sheep

Dolly, such as "messenger RNA", also because they were not used figuratively (by referring to another, more basic meaning of the word), but directly referred to a (biological) object (Giles, 2001).

The observation that specialist articles use the metaphors of "epigenetic marking" and "imprint" in a closed sense, while they are explained in non-specialist articles, is in line with Knudsen's theory that closed metaphors in specialist articles may be 're-opened' in non-specialist articles (even if a strict confirmation is beyond the scope of our analysis because we have not followed the origin of the relevant metaphors). Furthermore, this observation suggests that the conceptual mappings play a role in conveying understanding of epigenetics to both scientific and lay audiences, but in implicit ways for scientists, versus in explicit ways for lay readers. This confirms Knudsen's theory on the differences between closed and open metaphors (Knudsen, 2003).

5. Conclusion

Recent philosophy of science has witnessed a growing interest in scientific understanding. In our view, insights gained from these philosophical debates may shed light on the idea of public understanding of science, and how to achieve it. After all, successful realization of public understanding of science requires a clear conception of what such understanding consists in. Does it differ from expert understanding of science in kind or merely in degree?

In this article, we have attempted to answer this question by invoking the contextual theory of scientific understanding of science developed by De Regt (2017). This theory assumes that scientific theories must be intelligible to their users, in order to construct explanatory models of phenomena. Scientists need tools to render theories intelligible, and metaphors may provide such tools. To investigate similarities and differences between the way in which expert scientific understanding and public understanding of science is constructed, we have performed metaphor analysis on specialist and non-specialist scientific articles in epigenetics as a case study.

The results of our analysis of metaphor use in specialist and non-specialist scientific articles on epigenetics indicate that there is no substantial difference in frequency of metaphors on this topic and in their content (the concepts they refer to) in the texts examined for lay and expert audiences. These results are broadly in line with the findings of Nerlich et al. (2020). Our results confirm, first, that metaphors are highly suitable tools for rendering theoretical concepts intelligible, for both expert and lay audiences, since their primary function is to enable understanding of abstract concepts by relating them to familiar concepts. The results differ from those in Beger (2015), where the use of metaphors about LOVE and ANGER differed greatly between the contexts of academic lectures versus online counseling. There, though, the difference was not only one between academic and lay audiences, but also between spoken and written forms of communication, monologic lectures and dialogic advice columns (different discourse structures), and the function of teaching versus providing practical advice (different discourse goals). Beger attributes the differences in metaphor use in her data to these other factors.

Second, the overlap in metaphors in specialist and non-specialist scientific articles suggests that similar metaphorical conceptual mappings are used to convey understanding to expert and lay audiences, supporting our first hypothesis posed at the beginning. This could mean that scientific understanding of abstract concepts is conveyed to laypeople by offering the same familiar conceptual model that also played a role in the construction of expert scientific understanding. The different function of metaphors found in specialist and non-specialist articles (supporting our second hypothesis) suggests that experts have made this conceptual model their own while laypeople have not. This leads us to the hypothesis that scientific understanding of experts and laypeople differs *in the degree* to which a conceptual model of the relevant abstract scientific concept is internalized, rather than constituting different *kinds* of understanding. More research, also outside the field of epigenetics, is needed to substantiate this hypothesis.

Third, the centrality of metaphor in specialist scientific articles underlines its important role for the production of new scientific knowledge, as a tool to render abstract concepts intelligible. This agrees with the contextual theory of scientific understanding (De Regt, 2017), which emphasizes that the advancement of understanding requires that abstract concepts and theories are intelligible to their users. In line with this conception of scientific understanding, our results suggest that conveying understanding involves skills over and above knowledge: by relating new concepts to familiar ones, metaphors do not add knowledge in the context and data examined here but enhance relevant conceptual reasoning abilities. As such, the conceptual model for epigenetics that is constructed through the metaphors that are employed in the data could thereby facilitate further theoretical development. That is, the pedagogical purpose of metaphors found in the non-specialist publications (relating to our third hypothesis) consists in helping readers acquire new skills to understand the relevant concepts, namely new ways of reasoning about them. The conclusion that the understanding that metaphors stimulate involves reasoning skills, rather than mere factual knowledge, may serve as input into efforts to improve public understanding of science, given that the deficit model (with its focus on sharing of mere facts) has been shown to provide disappointing results.

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