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Scientific metaphors going public

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Abstract

Studies of scientific metaphors have largely focused on the existence, application, and function of metaphors in specialist scientific discourse, in some way overlooking the use of scientific metaphors in non-specialist discourses, in particular that of popularization. Richard Boyd (Boyd, Richard, 1993. Metaphor and theory change: what is ''metaphor'' a metaphor for? In: Ortony, Andrew (Ed.), Metaphor and Thought. Cambridge University Press, Cambridge, pp. 481–533) is an exception, however. He suggests the existence of two fundamentally separated categories of scientific metaphors: *theory-constructive* and *pedagogical/exegetical metaphors*. Whereas the theory-constructive metaphors represent original scientific thought and terminology, pedagogical metaphors merely describe or explain existing knowledge. The aim of this paper is to discuss the relationship between these two categories of metaphors from a pragmatic and empirical perspective. The analysis is based on a case study of the application of metaphors describing the genetic code and protein synthesis in three specialist and three non-specialist scientific articles. The study reveals that, depending on context and genre, exactly the same metaphors are used for theory-constructive *and* for pedagogical purposes. Consequently, metaphors should not be classified according to the individual expressions, but in relation to the developmental history of the specific metaphor, as well as such parameters or criteria as communicative purpose and genre.

Keywords: Metaphor; Academic discourse; Scientific conceptualization; Popularization

1. Introduction

''We are always looking for metaphors in which to express our ideas of life, for our language is inadequate for all its complexities. Life is a labyrinth...Life is a

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machine...Life is a laboratory...It is but a metaphor. When we speak of ultimate things we can, maybe, speak only in metaphors. Life is a dance, a very elaborate and complex dance..." (Singer, 1972: 489)

Our interpretations of, and experiences with, the world are widely influenced by the use of metaphors both in everyday and scientific reasoning and language use. The cognitive process of conceiving new metaphorical thought may be similar in both contexts, but the application and development of the various metaphors differ markedly from scientific to everyday situations. The acceptance and development of a specific scientific metaphor or network of related metaphors is extremely context-dependent in the sense that the specific scientific discipline determines the value of the metaphor. Because of the specialized purpose of metaphorical concepts in scientific discourse, such concepts need more or less immediate clarification. As a consequence, the exact meaning of a given metaphor changes over time within the discourse, and every established scientific metaphor is a result of a unique evolutionary history.

In specialist discourse, the dominant function of scientific metaphors is considered to generate scientific ideas, in so far as such metaphors are used to generate or construct hypotheses, ideas, and theories. The analysis of scientific metaphors thus provides important insights into the nature of the specific research discipline (cf. Koestler, 1964/1989; Hesse, 1963; Schön, 1963, 1993; Leatherdale, 1974; Martin and Harré, 1982; Keller, 1995; Paton et al., 1994; Paton, 1997). To use some of the more popular examples, a metaphorically structured hypothesis might characterize the atom as sharing essential properties with a planetary system. Similarly, an electric current might be understood as sharing important properties with running water. In scientific specialist texts, these analogically structured models are often (but not necessarily) represented by some form of figurative language, typically metaphors.

The specific cognitive process in analogical reasoning or analogical mapping in everyday and scientific reasoning is widely debated (e.g. Lakoff and Johnson, 1980, 1999; Gentner, 1983; Glucksberg and Keysar, 1990; Gibbs, 1992; Glucksberg et al., 1997) and recently an entire issue of the *Journal of Pragmatics* was devoted to this purpose [31(12)]. This debate is indeed both challenging and rich, but since any metaphor has a linguistic and a communicative aspect as well as a cognitive one, the present article will focus on the linguistic expression and application of metaphors in scientific discourse (as represented by scientific articles) and will rely more on a contextual, genre-based, and pragmatic approach than on a cognitive one.

Like any other scientific hypothesis, the newborn metaphorically structured hypothetical expression needs clarification; subsequently it is tested, accepted or discarded, questioned and extended in order to be scientifically applicable. This process of clarification may be repeated several times until the metaphor or the network of metaphors is officially considered scientifically acceptable. As a result of this developmental process, a change of status takes place. The experienced scientist within the field no longer considers the metaphor to be truly metaphorical; rather it becomes an almost literal expression with specific reference, similar to any other scientific concept.

Studies of scientific metaphors have largely focused on their existence, application, and function in specialist scientific discourse, thus neglecting the discussion and analysis of their application and purpose in non-specialist discourses, in particular that of popularization. The majority of studies of applied scientific metaphors in non-research academic discourses have focused on the application of metaphors for educational purposes. These studies reflect either the metaphors and mental models of individual teachers, or metaphors designed explicitly for pedagogical purposes (cf. Lindstromberg, 1991; Ashton, 1994; Bradford and Dana, 1996; Scruggs, 1998), of metaphors describing the teaching and learning processes (e.g. Volkman and Anderson, 1998; Stofflett, 1996; McMillan and Cheney, 1996; Siefert, 1995), or they discuss the application of metaphors in non-academic professional contexts (e.g., Wurtzbach, 1999; Nations and Monte 1996; Randels 1998). To my knowledge, very few empirical studies have dealt with the function and application of generative specialist metaphors in non-specialist discourse.

Boyd (1993) advocates the need to differentiate between two distinct categories of scientific metaphors. This differentiation is not based on an empirical study of the application of metaphors, but it does suggest interesting possibilities for such a study. According to Boyd, the generative or— to use his own term— theory-constructive metaphors constitute "an irreplaceable part of the linguistic machinery of a scientific theory" (p. 486). Theory-constructive metaphors are generally considered to be the most genuine scientific metaphors, because they form a unique part of scientific reasoning and conceptualization. Consequently, these metaphors are impossible to paraphrase, since they represent the only way of talking about a particular phenomenon or activity.

Theory-constructive metaphors may very well be the most unique or philosophically interesting kind of metaphor employed in scientific discourse, but they are not the only kind. Another group of scientific metaphors described by Boyd are the pedagogical or exegetical metaphors. Contrary to theory-constructive metaphors, the pedagogical ones can be paraphrased, since they only aim at explaining or illustrating a scientific phenomenon for which a perfectly adequate, alternative original expression exists. Pedagogical metaphors are neither original nor argumentative, but merely descriptive. Boyd (1993: 485) argues:

> There are, no doubt, a considerable variety of sorts of metaphors that play a role in science, and in theory change. Certain metaphors, which might be plausibly termed exegetical or pedagogical metaphors, play a role in the teaching and explication of theories which already admit of entirely adequate non-metaphorical (or at any rate less metaphorical) formulations. I have in mind, for example, talk about "worm-holes" in general relativity, the description of the spatial localization of bound electrons in terms of an "electron cloud", or the description of atoms as "miniature solar systems."

Paraphrase is the central tool in determining whether or not a given metaphor is absolutely necessary and indispensable in theory-construction. Boyd assumes the existence of two distinct and separated categories of metaphors primarily on the basis of their capacity of being paraphrased. A theory-constructive metaphor cannot be paraphrased without loss of information, because it is 'catachretic', in the sense that it fills a lacuna, not only in the discipline's scientific vocabulary, but in its mental model as well. A truly theory-constructive scientific metaphor is unique, whereas pedagogical metaphors can always be replaced by alternative or more original expressions.

> "It is the role of catachresis which, in an indirect way, is the reason why metaphor is so very useful in scientific theory-making, for (...) it is not the model itself as a heuristic device that makes models indispensable in creative theory-making, but the fact that the model gives rise to 'spins-off', a matrix of terminology which can then be used by the theorist as a probative tool." (Martin and Harré, 1982: 101)

The questions I wanted to discuss upon embarking on this study concern this categorization. I was wondering whether the two types of metaphor really are that divergent in nature, whether this categorization is as ironclad as Boyd suggests. And secondly, I wondered if a metaphor's status of being either theory-constructive or pedagogical is indeed that closely tied to the specific metaphorical expression itself, or if it might not rather be linked to the particular genre or context in which it occurs.

In order to decide whether any given scientific metaphor is truly theory-constructive, an empirical, diachronic study is needed, that is, a study of how the original metaphor was born, what purposes it was meant to serve, and how it developed from there. The present study is based on such an empirical, diachronic study of the metaphor, as used in molecular biology, of *the genetic code*; in particular, it focuses on the metaphorical extension of the notion of *translation*. I intend to discuss the nature of this categorization of theory-constructive and pedagogical metaphors from a pragmatic perspective; that is, by studying the use of metaphors in particular genres.

Several studies have shown that the function and application of linguistic, stylistic, and rhetorical features in academic texts vary according to genre (e.g., Rowan 1989; Myers 1990, 1992a, b; Swales, 1995; Hyland, 1998; Miller, 1998; Ben-Ari 1999; Phillips and Norris 1999). In order to discuss the classification of metaphors, in particular with reference to a non-specialist genre, I will present some results from a case study of the use of scientific metaphors in three specialist and three non-specialist texts. These texts present and discuss protein synthesis and the genetic code; they were published between 1962 and 1966, the period immediately following the breaking of the code, when the emphasis of research gradually changed from understanding the nature of the genetic code to researching specific instances of coding and coding units. The specialist articles appeared in *Science*, a prestigious weekly journal aimed at specialist scientists in a range of fields, while the non-specialist articles were published in *Scientific American*, a serious popular scientific journal aimed at an educated and scientifically interested lay-audience, and were written by the involved specialist scientists themselves, and not by the journalists of the more sensational popular scientific press.

Having presented examples of the application of metaphor in both genres (Sections 2 and 3), I intend to highlight two major differences in the application of the metaphorical material (Sections 4 and 5). The final Section 6 will reconsider the relations between theory-constructive and pedagogical metaphors.

2. Metaphors of the genetic code

The metaphor of the genetic code was introduced in 1944 in *What is Life?*, a tiny but very influential book by the physicist Erwin Schrödinger. The purpose of the metaphor was to hypothesize about the mechanism of protein synthesis, which was somewhat of a mystery at the time. Schrödinger wrote:

> "It is these chromosomes (...) that contain in *some kind of a code-script* the entire pattern of the individual's future development and of its functioning in mature state. Every complete set of chromosomes contains the full code; so there are as a rule, two copies of the latter in the fertilized egg cell, which forms the earliest stage of the future individual." (Schrödinger, 1944: 22—my emphasis.)

The metaphor of the chromosome code script is neither presented as a substitution for something else (an ersatz for the real thing), nor as an explanation of another scientific concept. The aim of the metaphor is not only to describe the chromosomes, but also to identify the function of the chromosomes by referring to the concept of code. The metaphor suggests to us what these chromosomes in fact do and how they do it. The breaking of the code, Schrödinger suggests, would enable us to understand the creation of life:

> "In calling the structure of the chromosome fibres *a code-script*, we mean that the all-penetrating mind, once conceived by Laplace, to which every casual connection lay immediately open, could tell from their structure whether the egg would develop, under suitable conditions, into a black cock or into a speckled hen, into a fly or a maize plant, a rhododendron, a beetle, a mouse or a woman." (Schrödinger, 1944: 22—my emphasis.)

Somewhat earlier in the text, Schrödinger had identified the target of the metaphor more specifically as *chromatine*—a mixture of deoxyribonucleic acid (DNA) and proteins. Whereas the non-figurative representation explains the chemical identity of the chromosomes, the figurative representation suggests what the chromosomes *do*: they encode the individual's future development.

The metaphor proved to be far from perfect, because the coding material of the chromosomes had already been identified as pure DNA and not as the mixture called chromatine. Consequently, Schrödinger had associated the metaphor of the code with the wrong chemical entity. Partly for this reason, in 1987 two of Schrödinger's colleagues, Linus Pauling and Max Perutz, questioned the value of his contribution to the development of molecular biological thought. (Pauling, 1987;

Perutz, 1987). Even so, and in spite of his chemically inaccurate metaphor, Schrödinger had in fact produced what no biochemist, molecular biologist, or geneticist had been able to produce so far: a metaphorically expressed, constructive hypothesis about the workings of the genetic material. This idea was to become extremely influential for our understanding of the nature of protein synthesis.

Schrödinger's metaphor was in need of conceptual as well as chemical clarification and strengthening in order to resolve *how* the codescript was capable of determining the production of proteins. In particular, more chemical knowledge of the structure of the DNA molecule was needed, and for the next ten years the metaphor was not developed further. In the mid-1950s, the physicist George Gamow came up with an extension of the metaphor. The specific mechanism of the code was argued to be *a translation process,* by which the nucleic acids of the DNA were simply translated into amino acids and protein. Gamow wrote:

> "(...) the problem reduces to finding a procedure by which a long number written in a four-digital system (four bases forming the molecules of nucleic acid) can be *translated* in a unique way into a long word formed by about twenty different letters (twenty amino acids which form protein molecules)." (Gamow, 1955: 1)

This new metaphor of translation cannot be paraphrased without loss of information. Actually, several additonal new metaphors are needed to explain and extend the code's original root metaphor. These metaphors of words, letters, digital numbers, and alphabets can in fact be paraphrased as molecular biological substances—in this case enzymes, amino acids, and the entire set of amino acids and nucleic acids.

Like Schrödinger before him, Gamow had invented a biochemically incorrect metaphor which had to be adjusted. The problem was that the process of translation turned out to require a two-stage, not just a single-stage, process (as Gamow had suggested). Gamow was unable to provide a functional alternative for this other process; as a consequence, the metaphor had to be temporarily abandoned. Between 1956 and 1962, additional metaphors relating to the code metaphor were invented, developed, and tested; this cyclical interaction between the construction of hypotheses, theories, and metaphors and biochemical research was to continue until 1962, when the code was finally broken, the structure of protein synthesis determined, and the alternative of a transcription, in addition to a translation process, could be provided. The result was a large conceptual network of more than 30 related metaphorical expressions, most of which are in use today. This metaphorical universe of related metaphors is what we mean when we talk about the metaphor of the genetic code, or simply the code metaphor.

As to the remaining metaphors, to discuss them would take me beyond the scope of this article, but I hope to have demonstrated the value of certain metaphors at least for the development of the genetic code. Furthermore, today these metaphorical concepts, despite their metaphorical origin, are no longer considered to be metaphors. A number of the molecular biologists I have consulted argue that, since they know exactly which chemical relations and substances are being referred to, the metaphors in question have lost any figurative quality they might have had. In the opinion of these scientists, no definitive difference exists between these metaphorical concepts and concepts with a mere non-figurative origin. Even though this point is well taken, and the majority of these metaphors have been accepted into the discourse as (almost) non-figurative concepts, they still have a common metaphorical history of being tentative, open, and possibly even ambiguous. Following years of clarification and application, they have gradually settled to become unequivocal and 'closed' (see Section 4, below) within a particular context. But what happens if they are used in another context? Are they presented and employed as scientific concepts—or as metaphors? The next sections will deal with this question.

3. Metaphors in popular science

In the early stages, molecular biology was very much in the public eye. Research was considered to be extremely important and promising and research results found their way into textbooks with unforeseen rapidity. In Conrad's words, "an appearance and allure of specificity privilege[d] genetic explanations in the public discourse." (Conrad, 1999: 228).

The present section presents a case study of the application of metaphors in six texts belonging to two distinct genres (scientific and popular scientific, with an emphasis on the latter) and dealing with the process of protein synthesis and the genetic code. The scientific texts were publishedin *Science*, and the popular scientific ones in *Scientific American*. Since neither journal is exclusively devoted to molecular biology, but covers almost any scientific discipline, the six texts may well be the journal's only articles during this period in which the code metaphor of the code is mentioned, both in the title and in the abstract. The articles were all published during the period immediately following the breaking of the code, when most of the groundbreaking metaphors had been constructed, chemically identified, and established within the scientific discourse of the times. The six texts are:

(*Science*)

- Sager, R., Weinstein, B., Ashkenanzi, Y., 1963. Coding ambiguity in cell-free extracts of clamydomonas. Science 149, 304–306.
- Nirenberg, M., Leder, P., 1964. RNA codewords and protein synthesis: the effect of trinucleotides upon the binding of s-RNA to ribosomes. Science 145, 1399–1407.
- Wilhelm, R., Ludlum, D. B., 1966. Coding properties of 7-methylguanine. Science 153, 1403–1405.

(*Scientific American*)

- Crick, F., 1962. The genetic code. Scientific American 207, 66–74.
- Nirenberg, M., 1963. The genetic code II. Scientific American 208, 80–95.
- Crick, F., 1966. The Genetic Code III. Scientific American 212, 66–74.

The existence and the molecular biological reality of the genetic code were not news in a specialist context at the time, but it was definitely still news to the public, hence obviously, the content and focus of the texts vary. Whereas the main concern of the non-specialist texts is to present and explain the general structure of protein synthesis, backed up by some of the central supportive findings, the main concern of the specialist texts is to discuss much more specific instances of the code. Consequently, the latter texts try to pinpoint exactly which amino acids and proteins are involved.

The two text genres are obviously similar in one respect: they use the exact same metaphors; outside metaphors are seldom introduced. About 90% of the metaphorical expressions used in both genres represent metaphors of the genetic code. Furthermore, none of the metaphors of the non-specialist text are original—they have all been recycled from specialist discourse. In the following section, I will discuss a significant difference in the use of the code metaphor on the basis of two examples, viz. the difference between what could be called an *open* and a *closed metaphor* both as regards linguistic form, frequency of application, and function.

4. Open vs. closed metaphors

When scientific metaphors are presented for the first time within a specific scientific context, they are clearly marked as ''strangers within the discourse'' (Soyland, 1994). They are tentative and potentially ambiguous, and they need explanation of some kind. The more thoroughly analyzed and established within the discourse a metaphor becomes, the more invisible the metaphor will appear. As mentioned above, once a metaphor is included in the dominant scientific mental model, the specialists no longer consider such an established concept, or *closed metaphor*, as a metaphor, and they use it just like they use any other scientific concept. Here are some examples:

> ''If similar mispairing occurred during *translation*, *messenger RNA* containing 7-methylguanine *would code* as if it contained adenine in place of the methylated base.'' (Wilhelm and Ludlum, 1966: 1403—my emphasis.)

> ''The system is based upon interactions between ribosomes, aminoacyl sRNA, and *mRNA* messenger RNA; SK which occur during the process of *codeword recognition*, prior to peptide-bond formation.'' (Nirenberg and Leder, 1964: 1399—my emphasis.)

The three metaphors (*translation*, *messenger RNA* and *code*) of the first excerpt and the complex metaphor of the second (*codeword recognition*) are all used as ordinary scientific concepts with specific referents without being in any way marked as metaphors. Notice also that the molecule called *mRNA* in the second example is presented in abbreviated form, thus obscuring its relationship with its metaphorical origin as *the messenger* or *messenger RNA*. In contrast in the non-specialist texts, we still find 'messengerRNA' being presented in quotes.

As we see, the specialist discourse exclusively uses closed metaphors. These closed, theory-constructive concepts are not marked in any way either as metaphors or as 'strangers within the discourse'. They stay in the background, are never explained or discussed, and their status as scientific concepts is indisputable.

Non-specialist communication represents a different communicative situation. Another linguistic strategy is required, by which the very same, 'closed' metaphorical expressions are re-opened in non-specialist texts. Such a contextualization, or explanation of the involved metaphors, is called for, since the readers' world (Phillips and Norris, 1999) is markedly different from that of the writers, in the sense that the intended reader possesses neither the relevant knowledge nor the vocabulary appropriate to molecular biology. In order to make sense to the novices, the text's scientific concepts need to be explicitly identified and explained, which is why closed metaphors are re-opened and explicitly represented in the text as metaphors, either in relation to a larger metaphorical universe or to a particular explanation in molecular biological terms.

The following three excerpts present such metaphors, highlighted *as metaphors* by the use of quotes:

> "It is only within the past 15 years, however, that insight has been gained into the chemical nature of the genetic material and how its molecular structure can embody *coded instructions* that can be "*read*" by the machinery in the cell responsible for synthesizing protein molecules." (Crick, 1966: 55—my emphasis, quotes in original.)

The new metaphor ("read") is marked as a 'stranger' because of its status as metaphor, not just because it represents a new conceptualization. (Compare that non-metaphorical expressions are not marked in any way, and that new conceptualizations, even when they are metaphorical, are not always and necessarily marked as such: the case of *coded instructions*, above, where the italics are mine). Next, I will present a non-established scientific metaphor:

> "They are four "*letters*" used *to spell out* the genetic message." (Nirenberg, 1963: 56—my emphasis, quotes in original).

As we see from this case, the decision whether or not to highlight a particular metaphor as a 'stranger' may be somewhat arbitrary. Similarly, in the example below, the metaphor of a genetic message is not emphasized in the original text in any way:

> "One can trace *the transmission* of the *coded message* from its original site in the genetic material to the finished protein molecule." (Nirenberg, 1963: 56—my emphasis)

However, on the next page, Nirenberg chooses to single out (by the use of quotes) exactly the same metaphor:

> "Leder and Nirenberg studied which amino acid, joined to its tRNA molecules was bound to the ribosomes in the presence of a particular triplet, that is by a "*message*" with *three letters*." (Nirenberg, 1963—quotes in original, emphasis mine.)

Establishing a connection between a particular metaphor and other related metaphors explaining the molecular biological processes is another way of marking the original metaphor as open. In the following excerpt, Crick is said to have explained the coding problem by referring to a larger metaphorical universe of letters, words and, reading, and to have followed up his explanation by a chemical identification of the letters.

> "In the October 1962 issue of *Scientific American* Crick described the general nature of *this code*. By ingenious experiments with bacterial viruses, he and his colleagues established that the "*letters*" in the code are *read off* in simple sequence and that "*words*" in the code most probably consist of *groups of three letters*. *The code letters* in the DNA molecule are the four bases or chemical subunits, adenine, guanine, cytosine and thyamine respectively denoted A, G, C, and T." (Nirenberg, 1963, 80—quotes in original, emphasis mine.)

My last two examples illustrate how one metaphor is explained in terms of another:

> "*The genetic code* is not the message itself but *the* "*dictionary*" used by the cell *to translate* from *the four-letter language* of nucleic acid to *the 20-letter language of protein*. *The machinery* of the cell *can translate* in one direction only: from nucleic acid to protein but not from protein to nucleic acid." (Nirenberg, 1963, 56—quotes in original, emphasis mine.)

> "Within the past year important progress has been made in *solving the* "*coding problem*". To the biologist this is the problem of how *information* carried in the genes of an organism determines the structure of proteins." (Crick, 1962: 66—my emphasis; quotes in original.)

In these cases, the metaphors themselves are no longer explained as such, they are simply used to convey the molecular biological realities explained or discussed in the articles. As the text unfolds, the metaphors in the non-specialist texts gradually become closed, since the reality of the described subject, both in the pedagogical as well as the chemical sense, now has been established. However, no matter how well-established the subject, the metaphors always remain potentially open.

In the non-specialist texts, both open and closed metaphors are employed to explain and describe the biochemical processes, whereas the specialist texts only use closed metaphors. Except for the metaphor of *genetic information*, all non-specialist metaphors enter the discourse as open metaphors. The initial sections of the non-specialist articles present open metaphors only, but as the texts unfold, previously explained metaphors tend to close up. However, since the nature of the genetic code, the coding units, and the coding process itself are the central themes of these articles, the corresponding metaphors retreat into the background entirely (as do many of the specialist metaphors): their purpose is pedagogical regardless of how the metaphors were used in scientific discourse.

5. Pre-theoretical metaphors

The most obvious difference between the use of metaphors in the two genres, as far as our case is concerned, is their frequency of occurrence: we find far more metaphors in *Scientific American* than we do in *Science*. The code metaphor is used 150 times in the non-specialist texts, as against 37 times in the specialist ones: an average of 50 metaphors per text in the former case vs. one of 12 per text in the latter. The articles are not compatible length-wise, the non-specialist texts being longer than the specialist ones; in contrast, about 3% of the words in *Scientific American* are used metaphorically, whereas only 1% of the words in the specialist texts are metaphors.

At the same time, the non-specialist texts use a larger variety of figurative language, introducing more than twice as many figurative expressions than the specialist texts do. Typically, non-specialist texts are more redundant than specialist texts, but redundancy alone does not explain the differences in frequency, since a substantial number of the metaphors (including a few similes and quasi-similes) in the non-specialist texts are of a very specific kind.

As to the new metaphors, these are often recycled pre-theoretical metaphors, which means that they are not really new at all to the specialist molecular biological discourse, where they originated during the mid 1950s, to resurface in the specialist discourse after a few years. Pre-theoretical metaphors are non-theory-constructive metaphors, originally created to form an analogical universe in which the theory-constructive metaphors could make sense. As soon as the central theory-constructive metaphors were experimentally and conceptually defined and established, the supportive pre-theoretical metaphors were no longer needed and they consequently disappeared from the specialist discourse. Following Boyd, we can classify these metaphors as pedagogical or exegetical. Since the majority of theory-constructive metaphors represent relations, the pre-theoretical metaphors were preserved in the discourse in order to express the interactional relationships of objects and their attributes (Aisenman, 1999; Gentner, 1983). In the example below, the pre-theoretical metaphors of a *long number written in a four-digital system* and *a long word formed by about twenty different letters* support and explain the theory-constructive metaphor of *translation*:

> "(...) the problem reduces to finding a procedure by *which a long number written in a four digital system* (four bases forming the molecules of nucleic acid*) can be translated* in a unique way into *a long word formed by about twenty different letters* (twenty amino acids which form protein molecules)." (Gamow, 1955: 1—my emphasis)

In contrast to theory-constructive metaphors, pre-theoretical metaphors may be paraphrased. In the examples above, the pre-theoretical metaphors express a relation between the sequence of nucleotides and amino acids on the one hand, and linguistic elements on the other, as we can see from the introduction of metaphorical expressions such as *letters*, *words*, *digits*, *sentences*, *dictionaries*, and *languages* into the molecular biological discourse (cf. Gamow, 1955, quoted above). While this category of metaphors is not represented at all in the three specialist texts, they are frequent in the non-specialist ones:

> "A protein is therefore like a *long sentence* in a *written language* that *has twenty letters*." (Crick, 1962: 66)

> "By ingenious experiments with bacterial viruses he Crick and his colleagues established that *the letters* in *the code are read off* in simple sequence and that "*words*" in *the code* most probably consist of *groups of three letters*." (Nirenberg, 1963: 80—my emphasis; quotes in original)

> "They are *four letters* used to spell *the genetic message*." (Crick 1966: 56—my emphasis).

> "*The genetic code* is not the message itself but the "*dictionary*" used by the cell *to translate* from the *four-letter language* of nucleic acid to *the 20-letter language* of protein." (Crick, 1966: 56—my emphasis; quotes in original)

In the original texts, such paraphraseable, explanatory metaphors were clearly kept away from the theory-constructive metaphors. Whereas the theory-constructive metaphors were represented without exception by genuine metaphors, the explanatory and supportive pre-theoretical metaphors were represented by similes, quasi-similes (Leech and Short, 1981; Wales, 1989), or in some other analogical form explicitly emphasizing the element of comparison. And while in the non-specialist texts, a few similes can be found, the dominating majority of the figurative language employed is metaphorical, regardless of its scientific status. The following example of a quasi-simile will serve as illustration.

> "On the one hand, the enzymes (proteins), the composition of which must be completely determined by the deoxyribonucleic acid molecule are long peptide chains formed by about twenty different kinds of amino-acids, *and can thus be considered as long 'words' based on a 20-letter alphabet*. Thus the question arises about the way *in which four-digital numbers can be translated into such 'words'*." (Gamow, 1955: 318—my emphasis; quotes in original).

The source (*long words*) and the target of the quasi-simile (*peptide chains*) are compared using the phrase: *can be considered as*. At the same time, the objects of the simile are emphasized in scare quotes ('*words*'), thus explicitly marking the concept as used in a non-literal way. In contrast, the relation between the involved objects is a relation expressed by the genuine metaphor of *translation*, simply because no other way of expressing that relationship exists.

The central communicative difference between the use of a simile and a metaphor in a scientific text is a matter of scientific *claim*. Whereas a simile claims similarity between the source and target, metaphors claim identity—obviously a much stronger claim. Psycholinguistic evidence (e.g. Aisenman, 1999; Gibbs and Water, 1990; Gentner and Clement, 1988) strongly suggests that a connection such as *like* is significantly different from one such as *as*. In Aisenman's words, "(...) these two structures reflect and impinge on different cognitive processes and are used for different purposes" (Aisenman, 1999: 47). Aisenman's experiments support the idea that simile is preferred to represent mapping of attributive predicates, whereas metaphor is favored in the case of relational predicates. These results furnish an additional perspective on the use of metaphors in science, since the theory-constructive scientific metaphors are relations between objects, whereas these pre-theoretical metaphors stand for objects which themselves are represented in the form of simile or linguistic analogy in specialist discourse (Knudsen, 1999).

In comparison, very few similes are employed in the non-specialist texts, despite the fact that here, the number of pre-theoretical figurative elements has increased dramatically. The majority of figurative expressions are metaphors regardless of their original function. It is not possible to detect any difference between theory-constructive and pedagogical metaphors, because all figurative expressions are used to *explain* the molecular biological and chemical reality of protein synthesis. The fundamental difference between a theory-constructive, generative and creative, conceptualized thought is simply no longer expressed; all the metaphors have become equal in status, to the detriment of the scientific depth perspective.

6. Results and discussion

While he never says so explicitly, Boyd (1993) seems to assume that theory-constructive metaphors and pedagogical metaphors are independent expressions, belonging either to one category or to the other. The results of the present study reveal that the borderline between these two categories is more fuzzy than initially assumed. This is not to say that genuine theory-constructive or pedagogical metaphors do not exist in a pure form, as can be seen when we apply the criterion of paraphraseability (see above, Section 2). The point is that any categorization of a metaphor has to rely on a pragmatic, diachronic analysis as well, because, as we have seen, theory-constructive metaphors can be used for pedagogical purposes, and—as will be suggested below—perhaps even the other way round.

Here, it is of particular interest that in the cases studied, identical metaphorical material occupied both categories and was used for both theory-constructive *and* pedagogical purposes. This would suggest that individual metaphors do not belong to different categories, but are capable of serving different purposes. Consequently, identical metaphorical expressions are capable of serving several purposes, dependent on context.

The present study has revealed a fundamental difference in the use of the very same metaphorical material in the two text genres, specialist and non-specialist. In contrast to the 'closedness' of the metaphors used in contemporary specialist texts, the metaphors of the non-specialist texts could be re-opened, such that their status as metaphors was emphasized, being either typographically marked as metaphors, or explained in relation to other metaphors used to illustrate the central properties and functions of biochemical and molecular biological substances. While the established conceptual metaphors were reduced to explanatory status, additional pre-theoretical metaphors were imported into the texts in order to further explain and illustrate the chemical and molecular biological realities (such as protein synthesis).

The fundamental change that occurs when scientifically established metaphors are used in popular scientific texts is their loss of status as scientific concepts. A 'democratization' has taken place, rendering all metaphors equal, regardless of historical origin and scientific status. Taking off from Myers's categorization of texts into narratives of nature and narratives of science (Myers, 1990), we might talk about 'metaphors of science' and 'metaphors of nature'. In my study, I hope to have illustrated how argumentative and theory-constructive metaphors of science are transformed into pedagogical and exegetic metaphors of nature, basically used for explanatory purposes, without any indication of their conceptual status. In addition, even the genuine theory-constructive metaphors of the discipline have become pedagogical or exegetic. When it comes to explaining this change, my guess is that the writers simply had no choice: they were forced to use these metaphors because the metaphors are indispensable for the writers' and scientists' actual understanding of the processes. Despite the subsequent 'closing' of the metaphors within the scientific discourse, they still remain active and open in the involved scientists' minds, when the latter were engaged in producing non-specialist texts.

Whereas the metaphors of specialist texts are either used as semi-literal concepts, or to *hypothesize about* Nature, the metaphors of non-specialist texts are used *to explain* Nature. Or, in other words: the theory-constructive metaphors of specialist texts represent hypothetical claims to be sustained by experiments. When it comes to applying metaphors in non-specialist texts, the process is reversed: these metaphors are—regardless of their original status within the specialist texts—used exclusively to explain Nature.

The next question is whether popular or pedagogical metaphors are ever used for theory-constructive purposes. To provide a bit more background for our discussion, let's consider the 'birth' of the code metaphor as it happened in 1944. Erwin Schrödinger, the father of the concept, created a metaphor which was actually pedagogical as well as theory-constructive. Though the metaphor could not be paraphrased, in all other respects it resembled the descriptive and pedagogical form of the popular scientific metaphors (being pre-theoretical and 'open', containing both quasi-similes and metaphor). On top of that, it was in fact introduced in a popular science text—which alone, in my opinion, is an interesting fact, because it suggests that creative, theory-constructive thought and communication are not the exclusive property of specialist scientific communication. Schrödinger's metaphor of a genetic codescript, being popular and theory-constructive, was truly suggestive and hypothetical, and it was taken as a challenge. But it was actually possible to paraphrase it, in the sense that Schrödinger himself presented alternative metaphors and provided analogies, describing the same phenomenon. (The metaphor of the code did in fact suggest properties that could not be adequately paraphrased, but at the time nobody realized this).

> "But the term code-script is, of course, too narrow. The chromosome structure is at the same time instrumental in bringing about the development they foreshadow. They are law code and executive power—or, to use another simile, they are architect's plan and builder's craft—in one." (Schrödinger, 1944: 23)

> "However little we understand the device we cannot but trust that it must be in some way be very relevant to the functioning of the organism, that every single cell, even a less important one should be in possession of a complete (double) copy of the code-script. Some time ago we were told in the newspapers that in his African campaign General Montgomery made a point of having every single soldier of his army meticulously informed of his designs. If that is true (...) it provides an excellent analogy to our case, in which the corresponding fact certainly is literally true." (Schrödinger, 1944: 23)

In a sense, we have now completed a full circle. The structure of protein synthesis originated from a pedagogical metaphor that was transformed into a theory-constructive one, which then again—given the right circumstances could, and would—be used all over in a pedagogical context. My point is that a neat and clear-cut distinction between pedagogical and theory-constructive categories of metaphors, independent of function, context, and purpose, may not be possible. Whether the metaphor belongs in one category or another does not depend on the specific metaphorical expression itself, but on the context and its purpose. The important issue in distinguishing between the different usages of the metaphor is empirical and diachronical: Was a particular metaphor in fact used for theory-constructive or pedagogical purposes, or even for both purposes at the same time—or was it not?

In some instances—like in the present case —, an alluring pedagogical metaphor may change the course of science; in view of the fact that the scientific disciplines of molecular biology and genetics certainly have dominated the past century, the application of this originally pedagogical metaphor eventually has changed our entire world.

> "Schrödinger had only clocks and telegraph wires (...) to think with. By the 1970's physicists, biologists, and engineers (as well as the rest of us) had a new kind of machine to think with, based not on unidirectional transmission of messages from sender to receiver but on networks and systems." (Keller, 1995: 108)

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