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Metaphorical concepts in molecular biology students' texts – a way to improve subject-matter understanding

Abstract

Earlier research brings evidence that metaphors facilitate our understanding of the world. In this study we explore Bachelor students' popular science articles on molecular biology with the aim to determine the frequency and nature of metaphorical concepts used in the articles. For this purpose, a comparative metaphor analysis of students' texts was conducted. The results show that only few students (5 out of 47) use metaphorical concepts when writing about complex molecular biological mechanisms to non-specialist readers. We discuss that the use of metaphors not only reflect, but may also support, the writer's subject understanding, especially when metaphorical concepts are created by the writer herself. We suggest that the invention of metaphorical concepts when explaining subject-matter to a layman could be a way for students to improve their subject understanding.

INTRODUCTION

Background

The ability to communicate subject-matter, not only with experts in the field but also with persons with a different educational background, is one of the highest valued skills in working life. This was confirmed in a survey among science alumni from Lund University (Pelger, 2010). In addition, *the ability to present and discuss information, problems and solutions in speech and writing in dialogue with different audiences* is one of the learning outcomes for a Bachelor's Degree, as stated by the Swedish Higher Education Ordinance (SFS1993:100, Annex 2). Yet, only little effort is made to let science students practice and improve the communication of their subject with non-specialists (Nilsson, 2012; Pelger, 2011; Pelger & Santesson, 2012). As a result, students' ability to communicate and explain subject-matter to a wider audience may vary largely. An analysis of popular science

texts, written by degree project students in Biology and Molecular biology, revealed a lacking ability among many students to write about their project to a layman (Pelger, Santesson & Josefsson, 2009). This may not be surprising, since the writing of popular science is usually not subject to systematic training in science education. Instead, communication in science education is dominated by the scientific language, although this has been considered to be the answer to why many students have difficulties learning science (Lemke, 1990; Nilsson, 2012; Strömdahl, 2013; Wellington & Osborne, 2001) – partly since some important features [that] are considered important from a learning and understanding perspective, should be avoided: “the many means of engaging interest, helping an audience identify with what is said, humanising a subject and making it more easily comprehensible that are not allowed in science” (Lemke, 1990, p. 131). Nonetheless, while scientific communication may hinder science students' learning, the writing of popular science has been shown to support their understanding of subject-matter (Pelger, 2011; Pelger & Santesson, 2015). Thus language, and the way it is used, makes an issue of high significance in science education.

In popular science communication, various rhetorical devices are typically used. One such device is the metaphor. It describes an object, by means of a mental image, with which it has something in common, by asserting that the metaphor *is*, indirectly, the unrelated object. It is this interaction between the tenor and the vehicle that comprises the core of the metaphor, where the tenor is the actual domain and the vehicle is the image. It has various purposes, but in science, the major aim of using metaphors is to concretise abstract information (Burkholder & Henry, 2009; Eriksson, 2014). For instance, in the empirical data (as will be presented below), the expression “Plant and fungus *form alliance*”, ‘form alliance’ would be the vehicle that represents the tenor ‘that plant and fungi collaborate, and live in symbiosis’ – an expression that, perhaps, does not generate mental images as the vehicle does.

According to the cognitive linguists Lakoff and Johnson (2003) metaphors are conceptual; they are so called *metaphorical concepts*, which organise structural systems in language that influence how and in what ways we view and relate to the world. Since language is an essential tool for both talking and thinking, metaphors may also influence our perception of reality. Hence they may influence the way we view molecular biology as well. For instance, we speak of the immune system in terms of an army, and we speak of DNA in terms of a book. Furthermore, a metaphor determines how reality might be interpreted, since the metaphor offers one way to look at it, while eliminating many other possible ways. Generally, the metaphor is believed to be a seductive linguistic element, rather than a way of thought or action (Lakoff & Johnson, 2003). The cognitive linguists, however, believe the latter:

We have found, on the contrary, that metaphor is pervasive in everyday life, not just in language but in thought and action. Our ordinary conceptual system, in terms of which we both think and act, is fundamentally metaphorical in nature (Lakoff & Johnson, 2003, p. 3).

Aim and research question

The aim of this study was to investigate the occurrence and character of metaphors, and in particular metaphorical concepts, in student-written popular science articles on molecular biology. The research question addressed is thus:

- What is the frequency and nature of metaphorical concepts used in molecular biology students' popular science texts?

THEORETICAL FRAMEWORK

Metaphors are being used everywhere, and thereby also in education, across the curriculum. That includes natural science and, more specifically, the field of molecular biology. In this field there are not only metaphors but also metaphorical concepts, as defined in the introduction. In the following sections we will give an overview of previous research on metaphors, and their significance to under-

standing. This research makes the background to the present study, where we further explore science students' use of metaphorical concepts in their writing.

Metaphors

The word metaphor originates from the Greek word *metaphora*, which means that something is moved from one place to another. In general, rhetorical devices are believed to make the language more beautiful, but more important, they may also be conceptual (Eriksson, 2014; Gross, 2006; Hellspong, 2011; Kjeldsen, 2008; Sigrell, 2008). The metaphor is, as mentioned above, an implied similarity between tenor and vehicle upon which the perception of the tenor is altered. Whether the metaphor is effective or not depends on the context in which it is used – if it is adequate and expressive with a communicative and elucidatory purpose, it will probably also be effective. From a didactic point of view, in the area of molecular biology, a metaphor should create a representative image of the molecular phenomenon without causing misunderstandings. Duit (1991) discusses advantages and challenges of analogies which apply to metaphors as well. Aside from facilitating understanding and generating cognitive images of abstract facts, metaphors should never reflect the scientific phenomenon in a way that may lead to misinterpretations. Although a metaphor may be accurate, it might still be misinterpreted if the reader interprets it in a different way than the writer intends. Moreover, finding adequate and inventing metaphors is not an easy process and the students probably need help and guidance when finding metaphors that are to represent scientific subject matter. It seems that metaphors are “double edged swords” (Glynn, 1989, p. 198) and this should be explicitly discussed in the classrooms. To summarise, metaphors are important pedagogical tools since they have the potential of making abstract knowledge accessible to both the expert and the novice. They should however be carefully and deliberately thought of before used in order to avoid misleading conclusions or an inadequate understanding of the tenor (Crick & Grushka, 2009; Hammer & Elby, 2003; Hedberg, Haglund & Jeppsson, 2015; Jeppsson & Haglund, 2013; Kjeldsen, 2008; Prelli, 1989; Rundgren, 2006; Rundgren, Hirsch & Tibell, 2009; Sidler, 2006).

One way of characterising metaphors is by the two categories primary and secondary metaphors (Burkholder & Henry, 2009). If primary, there is a root metaphor to which others within the same domain are related. If a metaphor is secondary, it is not a part of the current metaphorical concept (Burkholder & Henry, 2009). For instance, when discussing the immune system, the root metaphor would be “the body's national guard” where terms like “killer”, “attacking antibodies” and pathogens as “invaders” are primary. If metaphors outside the root metaphor – any expression that is not related to the national guard/military etc. – they would be secondary.

In addition, metaphors can be distinguished as either active or inactive (Bergström & Boréus, 2005). A well-known example of an inactive, or conventional, metaphor is the “cell”. Such a metaphor is “dead” as it is not thought of as a metaphor, even though it is. The metaphor *cell* (tenor: a little room or space) is, however, such an established expression today, and therefore one does no longer reflect upon its metaphorical origin. An active metaphor, on the other hand, such as “the cell's inner timer”, is non-conventional in its context, without which one would not be able to understand the metaphor. An inactive metaphor could, however, be understood without context (Bergström & Boréus, 2005; Eriksson, 2014; Rundgren, 2008).

In “Metaphors we live by”, Lakoff and Johnson (2003) mostly speak of, what we in this study describe as, inactive metaphors. They discuss numerous metaphorical concepts, where domain *x* is discussed in terms of another, domain *y*, which establishes a pattern that will be used when talking about *x*: time is money, argument is war and more is up are such concepts for instance. Moreover, these concepts will affect the understanding of the tenor: you are wasting my time (time is something you spend), I demolished his argument (arguing is something violent) and my income rose this year (what is going up is, usually, good). There are countless of examples to each metaphorical concept, provided by La-

koff and Johnson (2003). Because of all examples, comprising each metaphorical concept, this study suggests that the metaphorical concepts could be regarded as cobwebs, where the nodes of the web are the metaphors which comprise the concepts.

From a didactic perspective, it may be more relevant to look beyond the already existing metaphorical concepts and rather focus on the explicit, new and creative ones. Such metaphors can help to create a new perception of reality: *Thus, they can give new meaning to our pasts, to our daily activity, and to what we know and believe* (Lakoff & Johnson, 2003, p. 139). It therefore seems reasonable to assume that new metaphorical concepts could be of importance also in science education since inventing new metaphors, as a way of studying science, has to do with understanding. Haglund (2013) discusses this (self-generated analogies), as does Schön (1993) by means of the term “generative metaphor”. They both argue that such self-invented metaphors are likely to support understanding since the student does not have to interpret a metaphor but knows how the vehicle originated and in what ways it relates to the tenor.

A fundamental metaphorical concept in molecular biology is DNA. DNA is understood in terms of “the book of life” and the “genetic code” – a scripture from which life arises. The text is a code, and once the code is cracked the text can be read and understood. This inactive metaphorical concept, dna is o book, is supposed to be read, translated, copied and proofread. The three-digit code (a codon) is expressed as amino acids. These codons are what make up the genes, which can be read again and again – just like sentences – and they generate different events and stories. Sometimes genes can be excluded and be skimmed through while others are highlighted, depending on context and what the cell needs (Gross, 1990; Prelli, 1989; Sidler, 2006). This suggests that something abstract can be explained and understood to a greater extent through the use of metaphors.

In order to understand the metaphor, the receiver (the person who reads the article) needs prior knowledge about both the tenor and the vehicle. Without this knowledge the metaphor has simply no function. Metaphors may, thus, be interpreted differently depending on the receivers' connotations – to each and every word there are associations, but these are unlikely to be the same for everyone. Hence, the sender (i.e. the writer, the student) could never be certain that the metaphor is understood correctly and in the way she intends the metaphor to be interpreted. What similarities and differences come forth between the tenor and the vehicle? Are they the “right” ones? This being said, it is relevant that the metaphors are distinct, well-chosen and that possible misunderstandings are remarked on and discussed – but how can these hypothetical misunderstandings be known beforehand? In order for the metaphor to be interpreted according to the sender's intention, the sender must be as accurate as possible. As already mentioned above, the learner needs help discerning which aspects of the vehicle are relevant, and which are not, in a certain context – a metaphor is likely to break down at some point and this should be reflected on. Otherwise the comprehension of subject matter might be inadequate and go unnoticed which leads to inadequately conveyed information, both to the sender and the receiver. If the sender does not understand her own study, the chosen metaphor might be less appropriate and, consequently, this may lead to misunderstanding (Degerman, 2013; Glynn, 1989; Jeppsson & Haglund, 2013; Lakoff & Johnson, 2003; Strömdahl, 2013). *What is obscurely said, is obscurely thought* [authors' translation], Esaias Tegnér argued (1872). Thus, it seems likely to assume that the adequacy of a chosen metaphor reflects the subject understanding of the sender.

Learning through popular science writing

According to Vygotsky, thoughts come into existence through the means of language (Vygotsky, 1987). Writing helps to make our thoughts visible, and by writing them down we may trace back to them, and also have them developed and rephrased. Through the process of writing, associations could therefore be detected that were not acknowledged before, and which may lead to increased understanding (Dysthe et al., 2011; Nilsson, 2012). Especially, writing to a non-specialist audience, which means

placing complex subject-matter into a wider societal context, may support the writer's own understanding. This was found among students in Biology and Molecular biology writing popular science articles about their degree project (Pelger, 2011; Pelger & Santesson, 2015).

Popular science writing requires an ability to change perspectives, something that is worth considering from a cognitive point of view. Many perspectives of a certain tenor alter the pattern upon which the entirety of the tenor widens. Pattern-making, in turn, is beneficial to understanding since it creates a more complete entirety of whatever it is, and thereby makes it more accessible to mind due the clearer view (Gärdenfors & Lindström 2008). As could be observed among the degree project students, the widening of perspectives, achieved through popular science writing, contributed to the students' subject understanding and their scientific literacy (Pelger, 2011; Pelger & Santesson, 2015).

When complex matter is to be explained to a layman, metaphors are often being used. The use of metaphors may contribute, not only to the recipient's, but also to the sender's understanding of subject-matter. In a study by Rundgren (2008), it was shown that metaphors were used spontaneously by upper secondary school students, university students and experts when they explained molecular biological processes. Rundgren argues that information cannot be converted into knowledge until the new information is linked to previous knowledge in a meaningful way, a process that could be facilitated by metaphors. Metaphors help to make sense of empirical observations and theoretical explanations, and to communicate both with colleagues and the society. However, Rundgren claims that the function that metaphorical expressions, more specifically, have in molecular biology education, still needs to be determined (Rundgren, 2013; Rundgren et al., 2009; Rundgren et al., 2012).

Several studies conclude that metaphors do affect learning, and the potential of metaphors as a didactic tool has been widely discussed (Baake, 2003; Crick & Grushka, 2009). They are heuristic devices which facilitate learning by concretising abstract information through cognitive images, and should therefore be considered an important aspect of science learning (Duit, 1991). Yet, only little is known about this learning process, and the way in which metaphors, more precisely, may affect the understanding of subject-matter. We have not been able to find any previous studies on the correlation between metaphorical concepts and subject understanding; however, there is research on analogies and their correlation to understanding (Haglund, 2013), especially if their metaphorical aspects are emphasised (Duit, 1991). The purpose of the present study is therefore, as a first step, to investigate students' use of metaphorical concepts when writing to a non-specialist audience. In the next step, its effect on students' understanding will be explored.

METHODOLOGY

Educational setting

The popular science texts analysed in this study were written in a course context where students perform their Bachelor's project in either of the majors Biology or Molecular biology at Lund University. The projects are individually performed, and the assessment includes a scientific report as well as a popular science article. For most molecular biology students this is the first time they write a text in this genre. As a preparation to the task, a lecture is given where genre-specific traits are highlighted. Especially, the major differences between scientific writing and popular science writing are pointed out with respect to communication situation, content, structure and style. Various rhetorical devices, such as metaphor, alliteration, and personification, are described and illustrated as well. The assignment instruction also clearly defines the target group of the articles: upper secondary school students at the natural science programme.

Empirical background

The empirical data consist of 47 popular science articles written by bachelor students in Biology or Molecular biology. All articles were written during one year, 2013, and have a molecular approach. As

will be described in the Results section, metaphors were found in fifteen articles. These articles were further analysed with the aim to determine the frequency and nature of metaphorical concepts in the students' texts.

Study design

Hermeneutic and metaphorical content analysis methods were employed in this research. The purpose of hermeneutic analysis is to interpret and study the content and the structure of the text in order to understand it and the sender's underlying message, both what is said explicitly and implicitly (Ödman, 2007). This makes hermeneutics a suitable method for the present study since such an analysis allows for the subjective study of the empirical artifacts. It also allows for an analysis of the implicit, which is fundamental in this study since the analysis of metaphors includes the study of the un-said (Becker, 2008; Hellspong, 2001; Ödman, 2007).

The students' articles were approached, initially, with a close textual analysis (CTA), as a "pre-study" to the comparative metaphor analysis. CTA is a commonly used method in textual analyses and involves a close reading of the artifact that makes the interpretation of it easier, whereby a deeper understanding is achieved regarding why the artifacts are constructed the way they are and what the relation is between appearance and content of the artifact (Browne, 2009).

After the CTA, the analysis focused on the metaphors. First, the metaphors were distinguished and defined where tenors and vehicles were presented. Secondly, the metaphors were classified as active or inactive. Thirdly – if this was possible – the metaphors were categorised as primary or secondary. Finally, the articles' different metaphors were compared next to each other in order to distinguish similarities and difference between them that could either highlight or downplay different aspects of the analysis. Although the method is quite subjective, it still strives to yield intersubjective results – hence, the interpretations were compared to the context which will contribute to make the interpretations as probable as possible (Bergström & Boréus, 2005; Burkholder & Henry, 2009).

The analysis also showed other illustrative rhetorical devices which could not be strictly defined as metaphors, though – from a didactic point of view – they share the same communicative functions. In addition to pure metaphors, metonymies, similes and allegories were included ([Cicero], 2009; Kjeldsen, 2008; Sigrell, 2008), which means that a broad definition of metaphor was adopted in this study. In contrast, metaphors which were not regarded as relevant to the analysis, i.e. inactive metaphors, unrelated to molecular biology, were excluded.

The purpose of the comparative part of the analysis was to point out metaphorical similarities and differences between the students' articles. The comparative analysis operated within as well as between the articles. Each metaphor will be presented as *knowledge conveying*, *knowledge producing* or *knowledge creating*. These terms were invented for the study, based on the theoretical framework, and will be defined as follows.

Employed terms: Knowledge producing, knowledge conveying, and knowledge creating metaphors

The *knowledge producing* metaphor simply re-uses already existing metaphors, or brings knowledge about the tenor since optional images of how to understand the phenomenon are presented by the help of the metaphor, or both. Furthermore, if a metaphorical concept is created where all metaphors revolve entirely around a certain root metaphor, a cognitive pattern is formed upon which a new overall view of the phenomenon is obtained. According to the theory concerning acquiring an understanding of any given phenomenon (see section "Learning through popular science writing"), the cognitive pattern-making is important for the student in order to be able to understand the studied phenomenon. This does apply for the knowledge creating metaphors as well (Dysthe, Hertzberg & Løken, 2011; Pelger, 2011).

In contrast to the knowledge producing metaphor, the *knowledge conveying* metaphor is merely illustrating, describing and concretising subject-matter. A metaphor is especially knowledge conveying to the student (the writer) since it is that person who brings together the abstract fact with an everyday premise.

The *knowledge creating* metaphor is “active”, as it, in contrast to the knowledge conveying metaphor, creates a whole new way of approaching the tenor. Thus, an entirely new image of the tenor will be shaped, where the student herself connects abstract phenomena to everyday life.

The classification procedure can be exemplified by the categorisation of metaphors made in one particular quote, for instance “Fungi can also help plants against *hostile* organisms/*enemies* by using chemical *warfare*”, in the article by one of the students, S1. The metaphors (in italics) were interpreted by the given context in the article, and then they were classified as active metaphors which were knowledge creating, producing and conveying. They are all interpreted to be active since they do not appear to be part of a technical terminology. All were categorised as knowledge creating since organisms, dangerous to the plant are usually not explicitly discussed as *hostile* organisms, neither actual *enemies* nor that the fungi have a *warfare* against dangerous organisms. Therefore, these metaphors were regarded as new. They were categorised as knowledge conveying since they illustrate, describe and concretise subject-matter. Lastly, the quote was also categorised as knowledge producing – partly because all metaphors contribute to the metaphorical concept in the article, and partly since they bring knowledge about the tenors.

RESULTS

In this study 47 student-written popular science articles were analysed with respect to the occurrence and nature of metaphors. Due the purpose of the study, the articles with most metaphors were selected for a deeper analysis regarding the nature of each metaphor. Based on this criterion, fifteen articles of the initial 47 were collected. In the articles, approximately 220 metaphors were elicited all together, however only five articles included more or less developed metaphorical concepts (seven concepts in total). We have chosen three articles of the fifteen to illustrate the variation in this respect. The following quotes and metaphors, presented in Table 1–3, are excerpts from these articles, written by the three students S1, S2 and S3. The metaphors were analysed and classified according to the suggested model above. Only the article of S1 includes fully developed metaphorical concepts. This is contrasted to S2 and S3, whose articles lack fully mapped concepts.

An alliance or a symbiosis

Plant and fungus form alliance against plunderers (S1) is an article about how these organisms cooperate by exchanging qualities in order to survive hostile organisms. Meanwhile, the antibiotics that the fungus secretes are not only dangerous to the hostile organisms but also to the plant. In order to make the plant less sensitive, it is first exposed to cellulose, which seems to strengthen the plant. The student has investigated whether other plants also become strengthened when exposed to cellulose, which is relevant information if alamethicin (antibiotics) are to be used as pesticides.

In the article there are two metaphorical concepts: fungi and plants create an alliance and organisms which threaten the alliance are plunderers. The presented metaphors (Table 1) create these concepts because they all share the same common denominator; they all belong to the same metaphorical web. In an alliance (a military defense), one cooperates and takes advantage of each other's strengths in order to win a battle, and from this cooperation, both parts gain profit because they help one another in ways they themselves cannot, and without which they could not survive – as is the case with fungi and plants. They have a common enemy – a plunderer – which they fight against.

Table 1. Below, quotes with metaphors from the article of Student 1. The metaphors are interpreted, and categorised as knowledge creating, knowledge producing or knowledge conveying, as well as active or inactive. All metaphors presented below are primary, except for the last two.

Quote	Metaphor	Knowledge:	Active/ Inactive
Plant and fungus <i>form alliance</i> against <i>plunderers</i> .	<i>Form alliance</i> : plant and fungi collaborate. <i>Plunderers</i> : an intruder who takes something from the plants.	Creating Producing Conveying	Active
Many organisms can form <i>profitable relationship</i> .	<i>Profitable relationship</i> : different organisms have a close collaboration in order to survive.	Creating Producing Conveying	Active
It is a <i>win-win situation</i> for both the organisms since they <i>can take advantage</i> of each other's qualities.	<i>A win-win situation</i> : refers to the fact that organisms have close relations. <i>Can take advantage</i> : describes how such collaborations may work.	Creating Producing Conveying	Active
<i>In return</i> , the fungus receives sugar from the plant as a <i>reward</i> .	<i>In return... a reward</i> : to show the collaboration between fungus and plant, like a real relationship – they compromise.	Creating Producing Conveying	Active
Fungi can also help plants against <i>hostile organisms/enemies</i> by using chemical <i>warfare</i> .	<i>Hostile organisms/enemies</i> : organisms which are dangerous to the plant. <i>Chemical warfare</i> : fungus can, with chemical substances, eject the dangerous organisms, trying to destroy the plant.	Creating Producing Conveying	Active
The fungi secrete antibiotics which <i>needle/spike the attackers</i> .	<i>Needle/spike the attackers</i> : murders the dangerous attackers, just like snipers try to shoot down the front of the opponents' army.	Creating Producing Conveying	Active
The cell wall is a <i>barrier</i> .	<i>Barrier</i> : explains the cell wall's function.	Creating Producing Conveying	Active
Fungus can help a plant by forming <i>long strings</i> , for instance.	<i>Long strings</i> : the vehicle of the root system of the fungus and what it looks like.	Conveying	Active
Cell <i>wall</i>	<i>Cell wall</i> : describes the external coat – one talks about it in terms of a wall because what surrounds the plant cell shares qualities with a physical wall.	Conveying	Inactive

These quotes, all together, comprise what we call knowledge creating, as well as knowledge conveying and knowledge producing metaphorical concept. By using these metaphors in order to discuss the fungus-plant relationship, the author offers a particular way of looking at it – we understand it in terms of a war and a relationship. This contributes to a deeper understanding since the way of explaining creates a cognitive way of thinking where scientific facts fit. Usually one regards the hostile organisms as intruders or opponents in a war, but in general one does not regard them as plunderers – i.e. that the intruders penetrate the plant cell, steal its possessions and finally kill it. Through this metaphor, we view the phenomenon from a new perspective, which not only illustrates but also concretises and simplifies the complex molecular biological information.

The last two metaphors used by S1 are not part of the concept and therefore they were classified as secondary. However, they still have an illustrative function.

T cells or killers?

The article *The body's way of attacking itself* (S2) discusses what causes rheumatoid arthritis and how this disease may be prevented. The T-cells of the immune system are an important part of the progression of the disease.

In this article, there is a concept, the immune system is a military defence, which is based on an already inactive metaphorical approach since this is an already existing and frequently used conventional conceptual metaphor in molecular biology. The author writes about the immune system in terms of a real army, which not only protects the body from different kinds of intruders, but also agitators, such as cancer cells or an autoimmune disease (where the body's own cells believe themselves to be the enemies), such as rheumatism which the article discusses.

These metaphors (Table 2) were categorised as knowledge conveying and knowledge producing. Since the concept (and its metaphors) is used and accepted in the scientific sphere, they are not regarded as knowledge creating.

In the Discussion section we will return to the constraints of the metaphors used in this example, and suggest how an alternative choice of metaphors could more effectively facilitate understanding of the subject-matter.

A journey to DNA

Discovering genes, causing diabetes (S3), is an article concerning diabetes – which genes play a crucial role for the development of diabetes type II, and how could these genes be identified? Below, metaphors are presented which comprise a rudimentary metaphorical concept, diabetes (the illness) is a journey.

Table 2. Below, quotes with metaphors from the article of Student 2 are presented. The metaphors are categorised as described in table 1. All three are primary.

Quote	Metaphor	Knowledge	Active/ Inactive
The body's way of <i>attacking</i> itself. One can therefore wonder why some of these cells decide to <i>attack</i> its own body instead.	<i>Attacking itself/attack</i> : refers to that the body does something to protect itself which it does not benefit from.	Producing Conveying	Active and inactive
Our body is built from different kinds of cells, where some are meant to <i>protect us from intruders</i> , such as bacteria and virus.	<i>Protect us from</i> : some cells prevent dangerous organisms from entering the body. <i>Intruders</i> : organisms which usually are not a part of the body/which are not supposed to be in particular areas.	Producing Conveying	Both are active
With <i>agitators</i> such as these, one can get diseases such as rheumatoid arthritis where ones joints, slowly but surely, are damaged.	<i>Agitators</i> : cells which go against their nature, cells that are malware.	Producing Conveying	Active

Table 3. Below, quotes with metaphors from the article of Student 3 are presented. The metaphors are categorised as described in table 1. None are primary.

Quote	Metaphor	Knowledge	Active/ Inactive
Discovering genes, causing diabetes.	<i>Discovering</i> : finding and identify the genes, which are causing diabetes.	Conveying	Active and inactive
In many diseases, such as diabetes, genes <i>play an important role</i> in deciding who's going to get ill and how that happens.	<i>Play an important role</i> : explains that genes sometimes are crucial elements in a disease and that they are more crucial than environmental ones.	Conveying	Active
... to give every patient a more individualized health care which can <i>slow down the course</i> of the disease.	<i>Slow down the course</i> : to slow down the progression of the disease or stop it completely.	Conveying	Active and inactive
Diabetes is a metabolic disease where the body can't <i>regulate</i> the blood glucose concentration (blood sugar).	<i>Regulate</i> : to control	Conveying	Inactive
Or that the body's tissues no longer react to the <i>signals</i> of the insulin.	<i>Signals</i> : describes the fact that insulin affects the body's tissues and that they should detect the insulin but no longer do.	Conveying	Inactive
Genetic <i>information</i> .	<i>Genetic information</i> : DNA	Conveying	Inactive
The <i>purification</i> method of DNA.	<i>Purification method</i> : it means that one gets a solution of only solved DNA, instead of DNA and other components.	Conveying	Inactive
So that one can <i>wash away</i> unwanted substances and finally get the <i>pure solution of DNA</i> .	<i>Wash away, pure solution of DNA</i> : that such substances which are not DNA are removed.	Conveying	Both are active and inactive
By adding glycogen (sugar molecules which are <i>attached to one another/sit together/stuck together/are put together/are put together</i>) to the process.	<i>Attached to one another/sit together/stuck together/are put together</i> : that the sugar molecules are bound to one another in some way.	Conveying	Active and inactive

Why this only is a “rudimentary” concept (and not “completed”) is because: 1) there are too few metaphors and; 2) they are mainly in the beginning of the article. Moreover, the author uses many molecular expressions, such as *serum*, *nuclein acids*, *SNP* (*single nucleotide polymorphism*) and *genotyping*. The author tries to explain these rather complex expressions: *Serum* – blood where the blood cells and coagulation factors have been removed; *Nucleic acids* – DNA; *SNP* – short DNA sequences with different gene variants/combinations; *Genotyping* – a gene variant which an individual has got.

As has already been stated, the metaphors in this article are scarce. Those that occur are knowledge conveying since they describe the tenors in representative vehicles. Meanwhile, most of them are inactive. Examples that could be mentioned are ‘when one eats, the blood sugar/blood glucose *rises*’, ‘the insulin allows the body’s tissues to *take up* glucose’ and ‘SNPs binds to different *regions*’. We will return to these inactive metaphors in the next section, and discuss their limited potential of bringing conceptual understanding to the reader as well as the writer.

DISCUSSION

The purpose of the study was to determine the frequency and nature of metaphorical concepts in student-written popular science articles on molecular biology. Among the 47 analysed articles, fifteen contained metaphors. Metaphorical concepts, though, were found only in five texts.

Metaphors facilitate understanding by producing cognitive patterns and by introducing visual and concrete channels between the molecular and everyday language. Rundgren (2008), Rundgren et al. (2012) and Rundgren, Hirsch and Tibell (2009) argue that cognitive, internal images are important learning tools to molecular biology since they not only are useful when sharing information, but may also bring conceptual change. In the present study we further explore to what extent and in what ways students use metaphorical concepts when explaining molecular biology matter to a non-specialist reader. We conclude that few students make use of metaphorical concepts, as a way to support understanding – to the reader as well as to themselves.

By putting the information into a metaphorical concept, a certain way of viewing the information may be generated upon which the information is interpreted. Thus, the risk of misinterpreting the vehicle will be reduced. Furthermore, we advocate that a metaphorical concept may also implement a way of thinking and reasoning about the molecular biological process, which in turn might lead to the invention and creation of new vehicles (belonging to the very same metaphorical concepts which hence are broadened) since a chosen perspective of viewing the phenomenon dominates the thought. It might also be easier to critique the concept and to find possible vehicles that are not representative or concrete enough for the tenors. If the writer realises the advantages as well as the disadvantages of the concept, it may be easier to decide whether the concept is good enough to be used. Then, the sender might also foresee what possible interpretations (or misinterpretations) that the receiver may make from reading the metaphor in its context. In summary, it seems that metaphors which are nodes to a cobweb of a certain root metaphor (primary) are more concretising compared to those that are not (secondary) section.

In the following, we will discuss the constraints of the metaphors used in the texts of Student 2 (Table 2) and Student 3 (Table 3). We will also suggest how their use of metaphors could be explicated to support subject-matter understanding even more.

Students' use of metaphors: constraints and possible improvements

In the article of Student 2, the T and the B cells are presented as “protective cells” but they never become a part of the concept (the immune system is a military defence). It is a far too vague metaphorical expression since all cells, belonging to the immune system, are protective in one way or another. Alternatively, the author could have spoken of the T cells as killer cells or helpers, and the B cells as

fighter pilots who target the opponents with missiles. T killer cells are cells which find the intruders and kill them whereas the B cells are activated and starts producing anti-bodies, which seek out and target t intruders. As a result of this process, the immune system knows which cells/organisms to attack. The T helper cells activate and inform the B cells (commanders). Another reason why to expand the concept, and fit the T cells into it more accurately, is that “T cells” is an umbrella term (Widmaier, Raff & Strang, 2011). Which T cells is Student 2 discussing? The likelihood of misunderstandings would have been reduced if these two expressions were presented within the concept because then T cells would have been interpreted in a way Student 2 knows is correct. Furthermore, the T cells are a part of the key terms within the article and therefore the article would have been more comprehensible, both for the receiver and the sender.

The article is however not rich on metaphors. It would have been possible though to fit the study into the already established metaphorical concept, which would have made the molecular biology more concrete and easier to understand. But for this to be possible, the author him- or herself must be aware of this concept.

Among the fifteen analysed articles, the one written by Student 3 has one of the lowest frequency of metaphors, and those used were classified as inactive: When one eats, the blood sugar/blood glucose *rises*. No, it does not, but one talks about it accordingly because the measuring instruments work that way, both digitally and graphically; The insulin makes the body’s tissues to *take up* glucose – No, the tissue cannot grab anything since it does not have any hands, however the process of taking up glucose works in a way which makes it possible for us to talk about it in terms of grabbing something; Which binds to different *regions* – No, these are not places or regions, but the molecular facts can be spoken of like this because, even within molecular biology, there are limited and defined areas.

In comparison, the metaphors used by Student 1 may enhance understanding by producing cognitive patterns, and by introducing visual and concrete channels between the molecular and everyday language. By changing the way a word is used, in order to explain a certain tenor, the tenor will be understood accordingly, hence the metaphor creates new knowledge about it. As exemplified in the Results section, Student 1 uses “plunderers” instead of the more common metaphor “intruders” which changes how the tenor is interpreted and understood. Consequently, the writer may also gain a deeper understanding of the studied object as a whole since it is studied in a different and a more complete way. Here, plunderers make a better choice compared to intruders since plunderers imply that such organisms *take* something away (e.g. life, nutrition), whilst intruders simply *intrude* or *disturb* the plant – that is where the (perhaps more common and less active) metaphor “intruders” breaks down.

The understanding of the subject would probably become broader and deeper when using metaphorical concepts, not least for the writer. When writing, she discovers and develops a particular way of thinking, and it is the writer herself who relates the molecular biological phenomenon to her own subjective experiences and finds similarities in other domains. The writer is the only person aware of all vehicles which are representing the tenors, while the receiver only reads and perceives the vehicles present in the text. Hence, the receiver does never “have access” to all similarities and differences between the vehicles and the tenors. This might be an answer to why the writing process, while creating metaphors, is such an important step for learning since it allows for the writer to discover all similarities and differences.

It is also convenient that the writer is aware of images that are already a part of the reader’s mind. One might believe that some phenomena and molecular processes are clear to everyone, and that they do not have to be explained. That might be because the molecular biologist, as a writer, already possesses cognitive images and does not necessarily realise their complexity. To free one’s thoughts from visual connotations and associations is difficult, and it is a challenge to try to imagine what kind of pictures the receiver obtains from reading the words that the writer chooses.

The majority of active metaphors in the three examples were not classified as knowledge creating. However, there are articles where the writers have created their own metaphors which are new in the context they are presented. According to the theory (Crick & Grushka, 2009; Degerman, 2013; Hammer & Elby, 2003; Jeppsson & Haglund, 2013; Lakoff & Johnson, 2003; Nilsson, 2012; Rundgren, 2008; Rundgren et al., 2009; Strömdahl, 2013; Wolrath, 2012), an active metaphor created by the writer is the metaphor that gives the best and deepest understanding to herself, since (1) she has found an entirely new channel through which the tenor is understood, and since (2) a new metaphor, related to the same concept, is added to the metaphorical concept which then gains yet another node to the cobweb; such as fungi, by means of antibiotics, *needle/spike the attackers* which adds another creative metaphor to the concept fungi and plants create an alliance. Thereby, a more completed entirety of the molecular phenomenon could be obtained. Moreover, the creation of new, active metaphors requires that the student scrutinises possible alternatives. The passive re-use of established metaphors does not necessarily require scrutiny. Meanwhile that does not imply that inactive metaphors are not useful in a learning context but they might, perhaps, be more useful to a layman reader than to the writer. The inactive metaphor is more likely to be part of the writer's already existing vocabulary, and might therefore not be reflected upon as much as an active one since the inactive metaphor may already be integrated in the writer's everyday language. Thus, the writer's own understanding will, perhaps, be more favoured by an active metaphor.

Metaphorical concepts' significance to understanding

Conceptual metaphors are likely to be more useful than secondary ones since they pin-point the tenors, and therefore reduce the risk of misunderstandings, as conceptual metaphors are likely to create a more salient pattern, compared to the secondary metaphors which do not belong to the concept, and thereby do not steer the interpretation as much as the conceptual ones do. Furthermore, the conceptual metaphors approach the tenors from a specific perspective, whereas secondary metaphors tend to be more ambiguous, and thereby more confusing and imprecise. This makes secondary metaphors less effective – who knows how to interpret them correctly? It would have been fortunate if it was possible to determine why a certain metaphor does not work at times. However, it is obviously difficult to evaluate how the receiver interprets it and what prior knowledge the receiver has as well (Baake, 2003; Degerman, 2013).

Even the inactive metaphors would need to be studied more closely in case they are likely to entail misunderstandings, wrong connotations or misleading conclusions. It is also important that the metaphor consists of an adequate vehicle to the tenor, and that possible as well as inadequate connotations are discussed. If the writer herself does not know if the metaphor is inadequate, or if she decides not to use a metaphor at all, the text might be obscure and abstract. This may be the outcome if the writer does not really understand the subject-matter she is writing about.

All together, it seems reasonable to suggest that a metaphorical concept may contribute to a deeper and broader understanding, not least for the writer herself since: (1) metaphorical concepts produce a certain way of interpreting the tenors, which in turn reduce the risk of misunderstandings; (2) concepts create new content knowledge by putting the information into images, and thereby making the subject easier for the mind to grasp, and finally; (3) it is the writer who possesses the full reasoning process from which the vehicles arise that represent the complex tenors. The actual effect that the use of metaphorical concepts may bring to the writer's own understanding would thus make a relevant issue for future research.

Implications for science learning and teaching

This study may contribute to an improved learning of molecular biology since metaphors make this complex world easier to explain to laymen (within and outside the field) and moreover, as we discuss, they may also facilitate the writer's understanding. Conveying abstract information is, as stated

above, an obstacle for the students, which is why it is of great significance that a solution is deployed. It is reasonable to regard metaphorical concepts as one solution. In the present study, only a few students used metaphors when writing about complex molecular biology matter to a non-specialist circle of readers. As discussed above, the use of metaphors may not only facilitate the readers', but also the writer's understanding of this matter. Thus, science educators should perhaps encourage and train their students to use novel, knowledge creating metaphors in their writing assignments. Further research would, however, be needed before we can draw any conclusions about the actual learning that might be the outcome of this training.

Lastly, we would like to point out that this study does not suggest that scientific language should be abandoned. It is all about improving the learning process for those who try to learn, understand and explain molecular biology. Since scientific language seems to stand in the way of learning and understanding, then this language is what should be studied, analysed and used in a new, different and creative way. We should ask ourselves how we are to make molecular biological processes easier to grasp and understand.

The understanding of subject-matter that science students may gain when explaining their subject to others will be explored in a forthcoming study, with the aim to identify what favourable effects the use of rhetorical devices may have. Together, these two studies may constructively contribute to a deeper understanding of how language may facilitate science learning and teaching.

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