Death of metaphors in life science? - A study of upper secondary and tertiary students' use of metaphors in their meaning-making of scientific content

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Abstract

The study reported in this article investigated the use of metaphors by upper secondary and tertiary students while learning a specific content area in molecular life science, protein function. Terms and expressions in science can be used in such precise and general senses that they are totally dissociated from their metaphoric origins. Beginners in a scientific field, however, lack the experience of using a term of metaphorical origin in its domain-specific precise and general sense, and may therefore be more cognitively affected than the expert by the underlying metaphor. The study shows that beginners in the field of molecular life science use spontaneous metaphors and metaphors used in teaching in a way that demonstrates that they have difficulty using the proper scientific terminology. The results of this study indicate, among other things, that difficulties in science education may, to a large degree, be connected with problems of communicating the generality and precision of scientific terms and metaphors used in science. The article ends with a suggestion as how to enable students to move from general and vague metaphoric uses of scientific terms toward a more general and precise usage.

Keywords: Metaphors, Molecular life science, Communication

Introduction

To some extent, all learning means understanding something unknown in terms of something known. Evidently, learning is something much more than a mere cognitive understanding of something put into words. Learning can be a primarily bodily experience as learning to swim or to ride a bicycle, or a combined physical and auditory experience as learning to play the piano. However, in all those cases, new experiences are added to and filtered through prior experiences. You cannot learn to ride a bicycle without using your prior skills in balance and control of your limbs. The idea that prior experiences and knowledge are crucial for the ability to learn from new experiences and new information is a central notion in most theories of learning. Ausubel (1968) states that meaningful learning takes place when new information is coupled to existing knowledge. According to Dewey (1938/1997), we are constantly transformed by our experience, and our present experience is in turn transformed by our prior experience. This constitutes Dewey's principle of continuity, which states that "every experience both takes up something from those which have gone before and modifies in some way the quality of those which come after" (ibid p. 35). One way of relating something unknown to something known may be the use of metaphor – that is, explaining something in terms of something else. In science we also use our prior knowledge of the world to understand new phenomena or to understand known phenomena more in depth. The importance of metaphors and analogies in science teaching and learning has been extensively discussed in the science education literature (e.g. Aubusson, Harrison, & Ritchie, 2006; Clement, 1998; Clement & Rea-Ramirez 2008; Duit, 1991). However, in molecular life science education, the role of metaphors and analogies is less well studied.

In this investigation, we study how upper secondary and tertiary students make meaning of biomolecular visualizations (see Rundgren, 2008 for a fuller description of the study) related to the function of proteins. Here, we specially look closer at their use of metaphor to interpret the scientific content in a set of visualizations.

Metaphor and meaning-making

Metaphors and analogies (the term "metaphors" will hence be used to cover all metaphors, analogies, and similes) can be used to relate something unknown to something more well-known. Lakoff and Johnson (1980) have argued for the importance of metaphors for all kinds of understanding and meaning-making. According to them, the use of metaphor is central when learning abstract concepts, which can only be learned indirectly. Metaphors are ubiquitous in both written and spoken language.

We follow Lakoff and Johnson (1980) and other proponents of cognitive semantics in their claim that basic metaphors are established early in life when the human infant is exploring its environment. The infant notices that light usually comes from above and that there are many other good and rewarding things that come from above. The child is picked up and carried by its parents. When it is light, the world appears. When it is dark, the world disappears. We don't have very good night vision (as opposed to cats and owls) so we are more vulnerable to predators at night. What we cannot see may potentially harm or destroy us.

These ontogenetically primary and phylogenetically primordial experiences lead to a system of associations where well-being and security are associated with light, and danger and destruction is associated with the dark. These networks of associations are later used to express more abstract notions such as moral good and evil, joy and grief, intelligence and stupidity, freedom and confinement, and understanding and lack of understanding.

The important difference between our approach to metaphor and Lakoff and Johnson and other cognitivists is that we see the metaphors as constituting what were called "common places" in traditional rhetorical theory (Lausberg, 1990 p. 38-39). These "common places" are occurrences or phenomena that a speaker can reasonably trust that his or her audience, who shares the same physical environment and cultural background, will have some experiential knowledge of and will therefore be able to utilize in order to establish a consensus of belief with the audience based on this common experience.

We want to claim that the metaphors we examine in this article are enacted and embodied in the sense described above (the analogical bases are formed by the individual actively exploring his or her environment with the given perceptual apparatus), but that they are also distributed in the sense that they are shared with others, and interacted, in the sense that they are introduced and utilized in communication with others (they are not private property, but public means of communication). That is, they are inter-subjectively grounded in common experiences. The metaphors rely on the fact that there are obvious actual worldly phenomena that the communicators (teachers and students) assume they all know about and can be used, introduced and tested, as analogical models for the not so obvious and well known biomolecular phenomena and events they are trying to understand in this investigation. Importantly, things that are used as metaphors are not primarily or solely in the communicators' heads. These are things in the world that are good to use as models of other things, also in the world. What connect these things are the human communicators who are involved in a practice where certain things are being explored and described theoretically.

Living and dead metaphors

Metaphors appear as an essential part of any theorizing practice. Everyday conceptions and folk theories use everyday metaphors. Science utilizes metaphors that have been drained of their 'poetic' potential to a degree that we can say they have been conventionalized to death, at least when used by experts in the field. The metaphor has evolved from a 'living' to a 'dead' metaphor (Black, 1994). However, when experts use these 'dead' metaphors in communication with non-experts the metaphors may experience a "poetic" rebirth and lead to miscommunication and misunderstanding, which in particular can be the case for beginner students of an abstract area like molecular life science.

That a metaphoric expression can be conventionalized in a way that makes us forget its metaphoric origin is a normal and sound process. It would be inconvenient to constantly think about the metaphoric origin of a well-defined concept. Cell biologists uses the term "cell", for example, in their daily practice in its biological sense without any need to think about its metaphorical origins from an analogy between the cells of a plant seen using a microscope and the cells of a monastery. Beginners in a field, on the other hand, lack the experience of using a term of metaphorical origin in its subject-specific sense, and may therefore be more cognitively affected by the underlying metaphor than the expert. In other words, they may not yet have 'killed' the metaphors in the area. This poses an educational challenge for the science educator, who must be aware that a novice student understands an expression like 'covalent bond' differently from an expert who has a thorough experience of, for example, reasoning about chemical binding, molecular structure, and interaction between molecules.

A metaphor can be regarded as a good metaphor for different reasons. From a rhetorical point of view a good metaphor should be an image that captures the attention of the listeners by means of its poetic or otherwise striking qualities. From a scientific point of view a good metaphor is an image that makes an abstract scientific concept tangible and possible to handle by scientists, without distorting the scientific content. From a didactical point of view a good metaphor is an image that can be understood and used by the learners, giving a good approximation of the scientific content, without misleading the learners in their thinking. From the perspective of the student, a good metaphor is a metaphor which links the scientific content to his or her prior experience, in other words to the life-world of the student. The use of metaphoric language can constitute a bridge between the students' prior language and a scientific language. In some cases, these different points of view merge more or less unproblematically into one in science education. On other occasions it can be a question of context and audience whether you ought to stress the rhetorical, didactic, or scientific aspects of the use of metaphor; or whether you should take the perspective of the scientist, the policy-maker, the teacher or the student. A balanced use of metaphors needs to consider all these perspectives.

Depth of intention, precision, vagueness, specificity, and generality

Being able to use scientific terms is not necessarily the same as possessing an understanding of scientific content. However, terms may be a vehicle for abstract thought, and to acquire knowledge and skill in how to use a scientific language is certainly part of learning science.

Naess (1966) claims that there is often a difference in what he refers to as *depth of intention* in the statements made by an expert compared with the 'same' statements made by a novice.

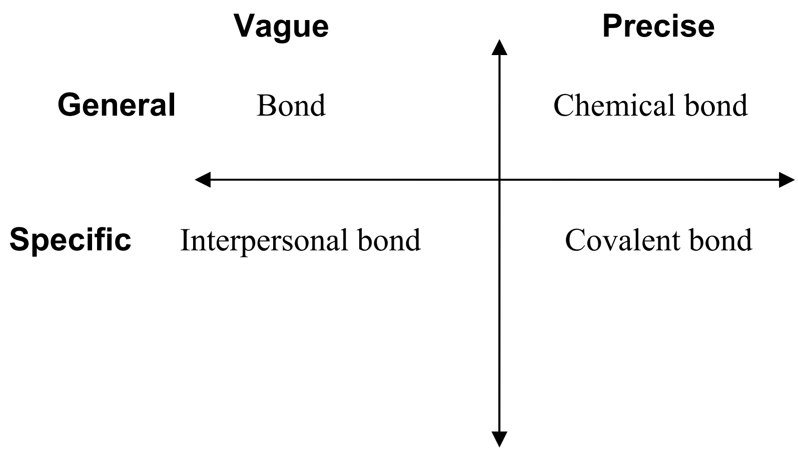
Depth of intention

The depth of intention equals the number of cognitive distinctions that a speaker or hearer is aware of and prepared to take into consideration in a particular situation in connection with the use of a particular expression or formulation (Hirsch, 1997 based on Naess 1966).

Although they may use the same terms, the underlying meaning is much deeper and richer in the language of the expert than in the case of the novice. The best way to determine depth of intention is, according to Naess, to let the interlocutors pose precise questions to each other in order to clarify what was intended by the use of the key terms. This discrepancy in depth of intention between the teachers and students can often be attributed to a lack of mutual common ground (Clark, 1996). Depth of intention in connection with a scientific term is grounded in a web of beliefs and wealth of practical experience shared by teachers and expert practitioners to which, students do not yet have access. The teachers' use of a term indexes this communal web of belief and wealth of practical experience whereas the students' use of the term indexes a situationally constrained, particular, and perhaps idiosyncratic understanding of the phenomenon described by the term.

In the analysis of meaning of terms it is necessary to make the distinction between vagueness versus preciseness on the one hand and generality versus specificity on the other (Naess, 1966). If we take the word 'bond', for instance, that occurs in both everyday language and the language of science we can make a four-way distinction between vagueness and preciseness, and generality and specificity as depicted in Figure 1.

Figure 1. *Model showing how the term 'bond' can be used with varying degrees of preciseness and specificity.*



In the figure, the everyday word 'bond' can be used in a vague and general sense to cover a wide range of references, where some of these are more or less metaphorical. The expression 'interpersonal bond' refers to a specific type of phenomena covered by the term 'bond' but not necessarily adding any precision to the term 'bond' itself. The notion of bond is still as vague as it was in the general case. In order to move in the direction of precision, what is needed is a regulation or regimentation of the term by a definition of the concept 'bond'. One case of this is the use of the term in connection with atoms and molecules, where the term 'chemical bond' refers to a certain class of phenomena in nature, covering different types of electrochemical forces between particles, such as ionic bonds, covalent bonds, and Van Der Vaal bonds. In this case, the concept of 'bond' has been explicitly defined. Using the precise expression 'covalent bond' we can refer to a specific type of chemical bond.

It is important, if not absolutely necessary, that communicators know to which area of the figure the term 'bond' belongs in order not to misunderstand or mislead each other. Confusing the vague and general sense of 'bond' with the precise and general can result in the creation of analogies that are misleading and irrelevant in a scientific context. The scientific term 'bond' has its roots in the everyday word 'bond', of course, but should not be identified with it. In the communicative practice of science, the scientific term has taken on a new much more precise and general meaning through the effort of generations of scientists striving to achieve a restriction of the associations and analogies that should be connected with the term in order to secure mutual understanding or at least rule out cases of serious misunderstanding.

The notions of precision, vagueness, specificity, and generality that we will be using in our discussion are defined as follows.

Precision, vagueness, specificity, and generality

Where A and B are expressions, either language (e.g. words, phrases, clauses, sentences) or gestures (e.g. pointing, illustrating, directly manipulating a real or virtual object)

B is more **precise** than A if and only if B is more clearly decidable in its application and non-application to any given entity or phenomenon within a domain than is A.

B is more **vague** than A if and only if B is less clearly decidable in its application and non-application to any given entity or phenomenon within a domain than is A.

B is more **specific** than A if and only if B denotes (refers to, illustrates) a class of entities or phenomena that are included in the class of entities or phenomena denoted by A.

B is more **general** than A if and only if A denotes (refers to, illustrates) a class of entities or phenomena that are included in the class of entities or phenomena denoted by B.

(Hirsch, 1989, 1996)

Terms belonging to everyday natural language tend to be vague and more or less general or specific in their range of meaning. The same term occurring in a scientific context is used in a more precise sense. The preciseness of a term relates to how well-defined the term is in relation to other terms that could be used to refer to a group of phenomena. The definition delimits the range of interpretations and applications of the term. Ideally, a precise meaning of a term should rule out borderline cases, in which it is not clear whether a certain phenomenon can be referred to or not using the term. How general the range of meaning is for a certain term relates to the range of phenomena in question that can be referred to using the term. If the term can be used to refer to all the phenomena, then the term is totally general. Usually, however, there are a number of less general terms (more specific terms) that cover various sub-areas of the range of phenomena in question. This usually results in a hierarchy or taxonomy of specific subtypes ordered under more general headings. A vague and specific deictic expression, like 'here' where it is often unclear exactly how the area referred to is to be delimited, is less general than 'somewhere' although both 'here' and 'somewhere' can only be understood with a proper knowledge of the particulars of the context of utterance. A precise and general term, like 'DNA', can, however, be interpreted by those knowledgeable in life science as referring to the same class of objects without any knowledge of the particular details of the context of utterance.

Precision, vagueness, specificity, and generality should, however, not be viewed as permanent properties of expressions but rather as relations that hold between expressions in specific contexts of use. An expression that is specific in relation to one term in a particular context may be seen as more general than another term in another context. An expression that is more precise than another term in one context may be vaguer than another term in some other context. Precision, vagueness, specificity, and generality should be viewed more as tendencies (vectors) in a multidimensional semantic space than as stable properties inherent to the semantics of individual expressions or terms.

Metaphors and knowledge

In science, metaphors are used in the *formation* of new knowledge. The use of metaphors can be a way of making it possible to approach and handle abstract scientific information, often expressed in a mathematical or visual code, more directly. This can be a tool for scientific thinking (Boyd, 1993; Hesse, 1963; Kuhn, 1993). For example, scientific discussion and thinking can be facilitated by conceiving of a DNA-molecule as a 'string', even though everybody who takes part in the scientific communicative practice understands that it is not a 'string' in the everyday sense of the word. Another example might be 'chaperon', which has made a transition from meaning an apron to an older person accompanying a younger (often female) person, to referring to a special class of molecules that decreases the probability that a newly formed protein will fold in an inappropriate way. Here, we refer to these ubiquitous metaphors as *metaphors used by the scientific community*.

When learners use metaphors in *acquisition* of new knowledge, the metaphors take on a different role. Here the educational and rhetorical aspects of the metaphor are its core value.

There is a wide variety of standard metaphors used in science teaching (Duit, 1991), and there is a continuously growing mass of metaphors invented by individual teachers. In this paper we use the term *metaphors used in teaching* for this category.

Apart from the metaphors used by teachers to facilitate learning, there is also a wide and wild flora of metaphors used by and invented by the students. Levin and Wagner (2006) differentiate between planned and spontaneous metaphors. While emergent metaphors, according to their classification, are spontaneous, planned metaphors are the product of a purposeful process of thinking and deliberation. Here we use the term *spontaneous metaphors* for all metaphors invented by the students, whether produced spontaneously or planned beforehand. A true distinction between planned metaphors and metaphors that are produced spontaneously requires a long-term study of individual students that lies beyond the scope of this study.

Furthermore, many verbs that are normally used in everyday contexts appear in learners' explanations in science (Cameron, 2002). Examples of such everyday verbs used in molecular life science are: 'cut', 'break', 'coil', 'copy' and 'translate'. Interestingly, these words are also used by the experts in the field, but then with a well-defined, precise meaning with an extensive depth of intention. These metaphorical expressions offer educational opportunities to link molecular processes to the life-world of the students, but at the same time they pose special problems due to the rich flora of everyday associations to which they connote. The challenge for the science educators is to make the students understand and apply the precision with which these terms are used in science. To achieve this, the students need to narrow the range of meaning of these terms, making them more precise and less vague. In other words, they must learn to 'kill' the metaphors in science. For example, for a beginner in bioscience, it may seem to be of little importance if they use the term 'break' or 'cut' when a DNA-molecule is divided. For the expert, however, 'cut' means a well-defined breakage of a binding, for example by a restriction enzyme which cleaves a DNA-molecule at specified positions; while 'break' means unspecific breakage, for example as the effect of exposure to radiation.

These verb-metaphors can be regarded as constituting special cases of spontaneous metaphors (when coming from the students), metaphors used in teaching (when coming from the teacher or text book author) or metaphors used in science – and thereby given a special, well-defined scientific meaning – (when coming from the area of science itself).

Although there is an extensive literature on metaphors in science education (Clement & Rea-Ramirez 2008; Duit, 1991), the spontaneous metaphors produced by the learners themselves have been less studied, although there are some exceptions (Bloom, 1992a, 1992b; Clement, 1998; Jakobson & Wickman, 2007).

The Empirical Study

The aim of the study was to investigate how the use of metaphors develops while students learn a specific content area, protein function. The study investigated how students reason around a set of visualizations of protein function and focused on the following research questions.

- How do students use metaphors in learning about protein function?
- Do student uses of metaphors change while learning about protein function from upper secondary to tertiary level?

Method

The context and sample

To be able to compare the effect of the pre-knowledge on the capability of making meaning of the visualizations, three groups of students were selected; students from an upper secondary school in a medium-sized town in southern Sweden, and university students from the same region. The upper secondary students participating (n=20) came from two upper secondary schools and were in the second (grade 11) or third (grade 12) year of their education. All upper secondary students were studying a natural science program or a combined natural science/social science program. The upper secondary students had studied various combinations of natural science courses, and consequently differed in their pre-knowledge to a relatively high degree. The university students (n=35) were in their first or third year of their tertiary education, studying chemical biology and had a relatively similar background knowledge. Our goal in the study was to choose students representing all levels of achievement (based on their grades in natural science subjects). However, since only a small number of students in each class volunteered to be interviewed, high-achieving students came to be over-represented in the study.

The scientific content of the visualizations used in the study

The following paragraphs describe briefly the content presented by the visualizations used in the study, all of which are highly simplified representations of proteins illustrating common functions of proteins rather than their structure.

The first diagram shows a cross-section of a cell membrane. The cell membrane consists of a bilayer of phospholipids, each of which has a polar part (which collectively forms the inner and outer surfaces) and a non-polar part (which constitutes the interior of the bilayer). The phospholipid bilayer also contains other molecules, primarily proteins. The membrane functions (*inter alia*) as a barrier that protects the interior of the cell from its surrounding environment. Small, uncharged molecules can readily move through the membrane without aid (via 'passive transport'), while charged and large molecules are 'locked out'. However, appropriate metabolites must be taken in and waste products removed. Much of the complex structure of biological membranes is therefore involved in the regulation of transport. In the visualization, three proteins acting as channels or pumps are shown in red. Through proteins such as these, various substances flow into or out of the cell in a controlled manner. The leftmost protein acts as a channel that facilitates transport of a substance (shown in grey), that diffuses in the direction of its concentration gradient. The middle protein allows transport of specific molecules, also in the direction of their concentration gradients, and the protein to the right transports a substance against its concentration gradient, in an energy-consuming process that is coupled to the breaking of energy-rich bonds in ATP molecules ('active transport').

The animation (http://nobelprize.org/chemistry/laureates/2003/animations.html) shown both in interviews and in individual exercises and group discussions visualizes the facilitated transport of water through a specialized channel protein, a so called aquaporine. The animation depicts the dynamic and random movement of the water molecules and provides an image of the large number of molecules that are constantly interacting.

The second diagram shows the process of protein synthesis in the cell. The process starts with the transcription of DNA into three types of RNA, which occurs in the nucleus (shown in blue). All three types of RNA are transported out of the nucleus, through the nuclear envelope, and out into the surrounding cytoplasm. The messenger RNA (mRNA) molecule (which carries the code for the corresponding protein) binds to ribosomal subunits which form a ribosome (shown at the right hand bottom of the picture). The other two types of RNA also have functions in the protein synthesis. The ribosomal RNA (rRNA) (shown to the right of the mRNA molecule), is an important constituent of the ribosomal subunits together with certain proteins, while transport RNA (tRNA; shown at the top of the picture) transports the various amino acids to the ribosome. There are multiple species of tRNA, each of which has an 'anticodon' (in the case shown three bases shown at the top of the molecule), which are uniquely matched to a specific amino acid. The tRNA molecules bind to the mRNA molecule in the ribosome in an order specified by matches of the sequence of bases in the mRNA to the tRNA's 'anticodons'. The amino acids so transported to the ribosome are connected to a growing polypeptide chain, which eventually forms a functional protein. The synthesis of proteins from mRNA is called translation. The information contained in the DNA is hereby expressed in proteins, with mRNA acting as an intermediary.

Data collection

Twenty upper secondary (16 girls and four boys) and four third-year university students (two girls and two boys) were interviewed using two diagrams and one animation. Consequently, there was an overrepresentation of girls (18 girls and only six boys) among the interviewees. The main reason for this is that girls were in the majority in the classes. In addition, 31 university students (16 girls and 15 boys) in their first year of studying biochemistry took part in an individual exercise, followed by a group discussion, centred on the animation of water transport. In the group discussions the students were divided into four groups in order to obtain groups of appropriate size, with 7-8 participants in each. The assignment to groups was made randomly, without any special connection to student performance.

Semi-structured, revised clinical interviews (Kvale, 1996) were used. The interviews were structured around the two diagrams of protein function redesigned from examples in text books used in upper secondary biology and chemistry courses, and the animation of water transport. Additional diagrams were also used, but the analysis concentrated on the diagrams of transport through the cell membrane and protein synthesis. The individual exercise and the group discussions focused on the water transport animation. In the interviews, the students were asked to interpret the visual representations using their prior knowledge. They were not given any specific information about the visual representations. All students were shown the same visual representations. Fourteen interviews also included the animation, which in some cases couldn't be shown because of technical constraints.

The interviews lasted for approximately 45 minutes and were audio-recorded and transcribed in full. An interview guide, highlighting certain topics of interest was followed. However, since an interview constitutes a conversation between different individuals, no interview guide should be too rigid — see the discussion about the problems of structured interviews by Mishler, (1995) — and no two interviews can be completely identical.

The individual exercise consisted of a questionnaire connected to the animation and generated written task responses. The questionnaire contained two sections. In the first, students were asked to interpret the animation without any clues. The second section contained information about what process the animation illustrated, and questions probing student understandings of the process and links to other processes. In the group discussion the same questions were discussed. The group discussions were video and audio taped and transcribed.

Data analysis

In the analysis on which this paper is based, the focus was on the students' use of semiotic resources, more specifically verbal semiotic resources such as scientific terms, metaphors etc. in their meaning-making of the content of the visualizations. The students' statements were categorized and colour-coded as deictic expressions, domain-specific expressions (scientific terms and metaphors used by the scientific community), metaphors used in teaching, and spontaneous metaphors. In the next step of the analysis, the colour-coded words were related to the context of the interview and from this an evaluation of whether it was part of a scientifically meaningful explanation or not was made. The transcripts were analyzed iteratively according to the method of analytical induction (Abell & Smith, 1994); they were read several times and categorized independently by two different researchers.

Results

In the following, examples are given of how students made use of metaphors in the interviews. 'CJ' stands for the interviewer and the students were allocated fictitious names.

Example 1: Maria (M) (year 2, upper secondary level) was asked to interpret the picture of a cell membrane, in which different channel proteins were visible. She replaces the scientific term 'receptor' with the metaphor 'flag'.

CJ: Can you tell me what's happening here?

M: Well, I know that the protein lets substances in and out of the cell, substances that are needed for transport processes and the construction of various things, and what happens is that the protein picks up those substances that are outside of the cell, it has these...*flags?*... that help it to identify the substances. I can't remember what they were called... something to do with flags in any case...

CJ: OK

M: ....and they act as signs so that the cell knows which substances are available and which should be taken up, and the protein itself can open to form a channel to let the useful substances in and then close again to stop other things from getting in. The protein can also transport things out of the cell.

CJ: These flags – are they on the molecules that the cell wants to take up?

M: No, they're on the cell wall, I can't remember. It's like... I don't know. In any case, I can't remember properly, but they sort of sit on the outside of the cell and detect which substances are out there and which it wants to take up, and they take care of that. And the protein itself is like a pump that lets things in and out, and makes sure that neither too little nor too much is allowed into the cell, it opens and closes.

Example 2: Jonas (J) (year 3, upper secondary level) is asked if he can visualize a protein. He makes a metaphoric association to a wadded-up ball:

CJ: If I ask you to think about a protein, does any sort of image spring to mind?

J: Yes, it does. We've seen pictures in biology - a sort of *ball*, I guess, like *a wadded-up ball*, except that the *threads* are *chains of amino acids.*

This spontaneous metaphor reoccurs later in the interview when he is shown a picture of a folding protein:

CJ: Exactly. And what do you see on either side of this picture?

J: So you've got the *wadded-up ball* on one side, and a non-wounded-up *string* or *thread* on the other....

Example 3: Erika (E) (year 3, upper secondary level) is shown the visualization of the process of protein synthesis. To describe the conformational change in DNA at the beginning of transcription, she makes a metaphoric association to a ball of yarn.

CJ: Do you recognize this picture? Do you know what it represents?

E: Yeah.... it's DNA, transcription and stuff...

CJ: Yes, quite. Could you tell me what's happening? If we start here, with the DNA in the nucleus, can you tell me what happens here to begin with?

E: Hmmm, I'll have to think.... to begin with, it's all *wrapped up like a ball of yarn*, and then it folds itself up, I think.

CJ: Do you mean the DNA?

E: Yeah, the DNA

The metaphors in the examples above are:

Erika: *Wrapped up like a ball of yarn*, a spontaneous or teaching metaphor which describes the conformational change in the DNA at the start of transcription. Beside the metaphorical association to a ball of yarn, Erika uses a verb, *wrap up (veckla upp)*, which connotes to everyday events.

Jonas: *A wadded-up ball*, a spontaneous metaphor which he uses both as a description of his mental image of a protein and to describe a visual representation of a folding protein. The fact that he uses this spontaneous metaphor twice during the interview seems to indicate that it connects to something central in how he perceives a protein. It can also be noted that his addition of the adjective 'wadded-up' makes the metaphor more specific and also slightly more advanced, and thus a better description of the three-dimensional structure of a protein molecule, as compared to the simple metaphor 'ball', which merely refers to a rounded sphere.

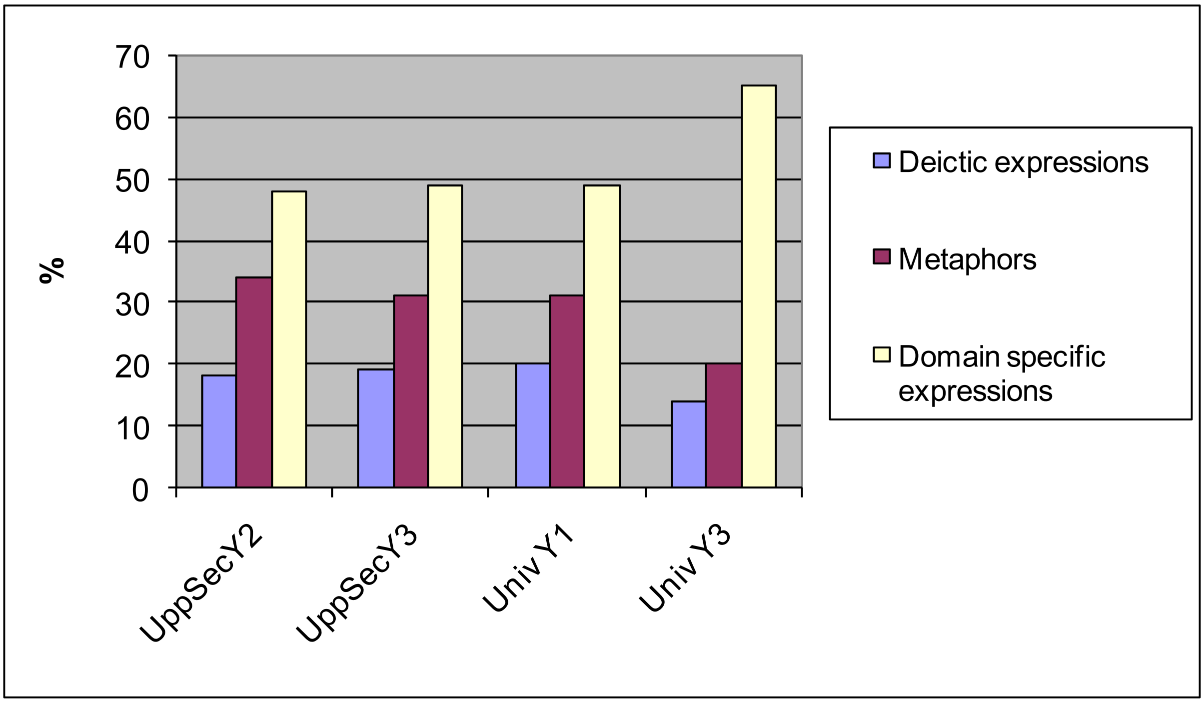
Jonas: *threads, chains of amino acids*, which Jonas uses to refer to a protein molecule, metaphors that are also used in science.

Maria: *Flag*, by which she describes a structure projecting from the outside of the cell membrane (which she by a slip of tongue calls cell wall' instead). From her reasoning it is possible to determine that she uses the metaphor 'flag' to signify the biomolecular concept of *receptor*. When she was later asked what she had intended with the word 'flag', it could be confirmed that she actually meant 'receptor', although her conception of receptor seemed to be vague – which is natural at upper secondary level, as the receptor concept is examined more in depth first at tertiary level. She recalled that she had got the metaphor 'flag' from a certain section of a prior course in natural science, and that the metaphor had been introduced by her teacher. Furthermore, from the transcript, it seems likely that she confuses the concept of specificity of channel proteins and the concept of surface receptors.

It is a striking feature of the interview transcripts that the students actually reason in a way that shows that they have grasped important aspects of the scientific content, at the same time as they have difficulty in using the proper scientific terminology.

In answer to the question whether the students' use of metaphors changes while learning about protein function from upper secondary to tertiary level, the results presented in Figure 2 show that the use of metaphors decreases, while the use of domain-specific expressions increases. Deictic expressions used to refer to various aspects of the animations remain relatively stable, albeit slightly decreasing, over time with increasing level of education.

Figure 2. *The relative frequency (%) of use of the four categories of expressions: Deictic expressions, Metaphors and Domain-specific expressions by the upper secondary and tertiary students in this study. (n=55)*



Discussion

According to our empirical material, the concept of 'protein' can be referred to by students using several different terms (see Figure 3), ranging from scientific terms to metaphors and deictic expressions. However, the depth of intention with which the term is used cannot be judged from inspecting the term in isolation, but rather by an investigation of the context in which the term is used and in what way it is being used.

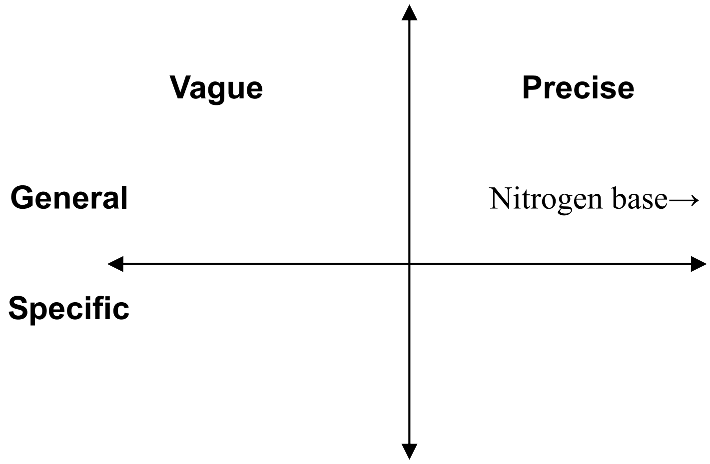
A protein can in different contexts be referred to as:

Figure 3. *Model showing the continuity between metaphors and deictic expressions. The line extends from a more abstract, general and precise meaning on the left to a more vague and context-specific meaning on the right. From Rundgren (2006).*

A chain of amino acids	A necklace with beads	A wadded-up ball	It
←-------------------	-------------------	-------------------	-------------------→
Metaphors used by the scientific community	**Metaphors used in teaching**	**Spontaneous metaphors**	**Deictic expressions**

In an investigation of the context in which a term is used, it is possible to discuss the range of meaning, i. e. the specificity and generality or the vagueness and preciseness of the term. Let us look more closely at five terms used by the students in the investigation:

Figure 4. The model in Figure 1 applied to the scientific term 'nitrogen base', as it is used by the scientific community.



The term nitrogen base refers to a certain chemical compound that is a constituent part of the DNA and RNA molecules. There are four types of nitrogen bases in DNA and RNA, respectively, and their order determines the genetic information conveyed in the molecule. The concept of nitrogen base as a chemical compound and its function in the biochemistry of life is well established and defined in current science. Therefore, the meaning of the term 'nitrogen base' is general - it always refers to all entities of a certain kind – as well as precise (meets explicit criteria) - the referents are clearly defined, and there are no borderline cases (see Figure 4).

Figure 5. The model in Figure 1 applied to 'flag', a metaphor used in teaching by Maria's teacher to convey the concept of 'receptor'.

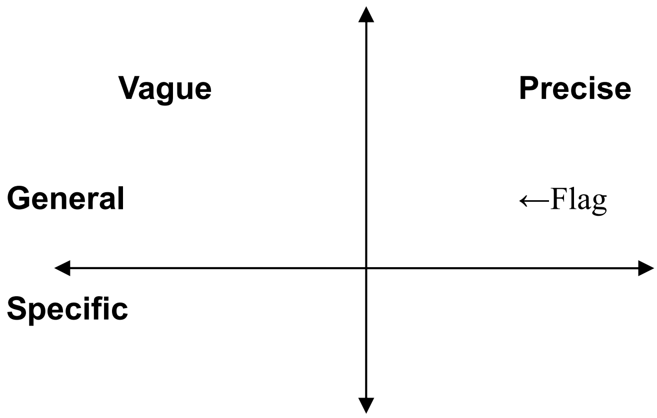
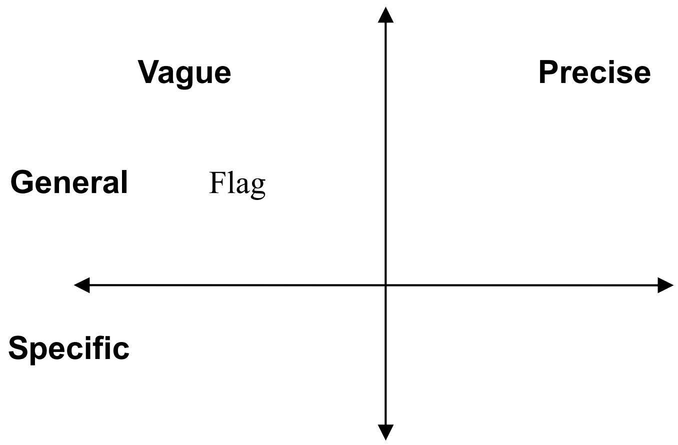
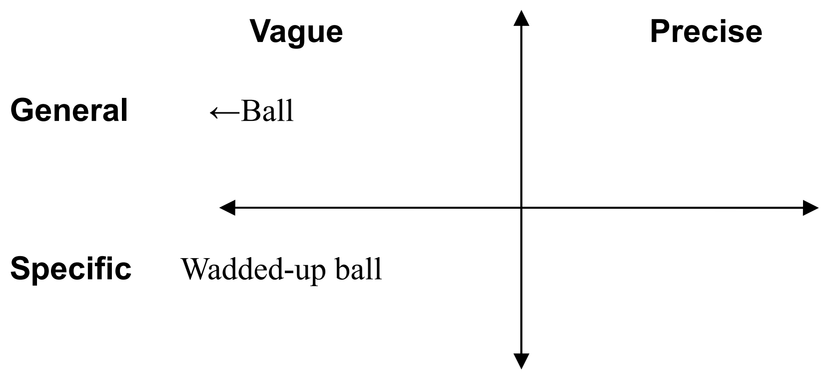


Figure 6. *The model in Figure 1 applied to 'flag', as Maria uses the metaphor introduced by her teacher.*



In the interview, Maria uses a metaphor from teaching, *flag*. When used by her teacher as a metaphor for receptors on the cell surface, the metaphor is actually quite precise in meaning (see Figure 5). However, when Maria uses the term (see Figure 6), the meaning is more vague. She uses the receptor concept in a context where she should actually speak about selective transport through channels, rather than about receptors. At the same time, she conveys a certain degree of understanding of the receptor concept, although the depth of intention with which she uses the term is less than that of her teacher. Still, without fully grasping the receptor concept, she uses the metaphor 'flag' with enough precision to make it possible for a person with adequate content knowledge to interpret the intended target of the metaphor. Outside this context, the word 'flag' has a wide range of meaning and refers to a number of objects that can be referred to as 'flags'. In the everyday usage of the word, there can be a number of vague cases, such as a facial paint and waving cloths among football supporters. But as Maria uses the term here, we can distinguish a group of referents – receptors. At the same time, it is clear that she uses the term with a relatively less developed depth of intention as compared to an expert in the field.

Figure 7. *The model in Figure 1 applied to the metaphors 'ball' and Jonas' spontaneous metaphor 'wadded-up ball', both referring to a protein molecule.*



The metaphor 'ball' refers to a wide array of objects. Its range of meaning is general, as it can be used to refer to all kinds of rounded objects, in this case molecular structures depicted as rounded shapes. Furthermore, the meaning is vague, because it is hard to make any exact definition of what can be referred to as a 'ball' and what cannot (see Figure 7). For example, if a child kicks a ballon, is it proper to call it a 'ball'? Or what would we say if the same child uses a wadded-up newspaper? The terms of our everyday language often tend to have a vagueness and elastic quality that make them applicable in many differnt situations.

Jonas uses a metaphor, 'wadded-up ball', which makes the utterance more specific than the general metaphor 'ball', which in this context merely refers to a rounded shape. The addition of 'wadded-up' makes the possible group of targets to which the metaphor can refer more restricted. However, we must ask whether it makes the metaphor more precise. Our interpretation is that the metaphor has a relatively low degree of precision. It is specific rather than precise, because it must be seen in the proper context of the utterance to be understood correctly (see Figure 7). It has higher specificity than the simple metaphor 'ball', because the group of possible referents is more restricted. However, the metaphor is vague rather than precise as the referents are not clearly defined. There has been no attempt to delimit the central notion of 'ball'. How round or non-round, how large or small, how smooth or rough, how solid or hollow, how elastic or non-elastic, is the 'ball', for instance? Without these delimitations, there might be a number of borderline cases in which the application of the term 'ball' could be uncertain or undecideable. Is a grain of sand a 'ball'? Is the Globe in Stockholm a 'ball'? In order to gain in preciseness, an expression must have less problematic borderline cases.

From novice to expert – 'killing the metaphors'?

Goodwin (1994; 1995) has shown that deictic expressions are used to a high degree by professionals. In our data, deictic expressions are used approximately to the same degree by the different groups (see Figure 2). This may be connected to the presence of the visualizations in the interviews, which makes it easier to refer to an object or process by a deictic expression than by using the standard scientific terminology. The results indicate that the third year upper secondary students were able to retain a functional, process-related understanding of the content they studied one year before. Although, they found it at times harder to remember and use the proper domain-specific expression for the phenomena. By using the visualization and metaphors (which both probably also acted as a support for memory), and deictic expressions, the students were often able to give a satisfactory description in general accordance with the scientific understanding of the phenomenon, taking, of course, the learners' level of education into account. However, the use of spontaneous metaphors and metaphors from teaching were lower at higher levels, and the results indicate a decrease in use of these kinds of metaphors, while the use of domain-specific expressions, among them many 'dead' metaphors, increases with higher levels of education (see Figure 2). The novice or learner moves away from spontaneous metaphors and metaphors used in teaching toward domain-specific terms when gaining in proficiency or competence. Experts can, however, return to the metaphors, relaxing the domain-specific terminology, in order to facilitate communication among themselves or when communicating with non-experts, but using the metaphors with a much more extensive depth of intention than the novice.

The language used in science textbooks is necessarily general and (at least ideally) precise. This general and precise terminology may however cause problems for students, whose interpretation of the terms are more vague and specific. It is more difficult for a novice to grasp in which way a term is precise (conceptually well-defined and delimited), at the same time as it is general (not limited to specific contexts). The precise terms and dead metaphors used in scientific language may be given unwanted connotations to everyday meaning by learners, thus causing difficulties in communicating the meaning between the teacher and the students. The teacher and students may therefore be talking past one another; the students not grasping the precise meaning and the teacher not fully recognizing the lack of precision in the students' use of the scientific terminology. The abundance of students' alternative conceptions discovered by science education research (Duit, 2008) is to a large degree connected to the problems of communicating the preciseness of scientific terms.

It is hard for a novice to go straight from a vague and general to a general and precise meaning of a term. One way of achieving this is to start the learning process by using the term in specific contexts and showing the learners how it can be used. In the case of molecular life science, visualizations such as those used in this study may be one way of specifying abstract and general concepts. An animation showing how DNA is unspecifically *broken* by UV radiation and specifically *cut* by a restricion enzyme might be one way of specifying, and, through more experience, making the meaning of *break* and *cut* in molecular life science more precise. The aim is to enable the learner to make a U-shaped turn in the model presented in Figure 1, starting in the upper left corner with an everyday, general and vague, meaning of *break* and *cut* ; being given a specific example; precifying the meaning of *break* and *cut* in this specific example; and finally reaching a precise and general meaning of *break* and *cut* through generalization of the use of these terms in several different situations.

In conclusion, this study has shown the importance for educators to take into account the difference in depth of intention between different individuals while using the same term. To use a scientific term is not necessarily equivalent to using it with a more extensive depth of intention. Furthermore, it supports the idea that it is of high value in educational contexts to be explicit about the range of meaning of a certain term or metaphor, and to be clear about what makes a domain-specific term precise instead of vague.

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