The cognitive role of metaphor in teaching science: Examples from physics, chemistry, biology, psychology and philosophy

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Abstract: In her seminal work *Models and Analogies in Science*, Mary Hesse (1966) establishes an important function of metaphor in scientific theorizing – the explanatory function of metaphor in scientific models. While Hesse was concerned with scientists communicating with each other, this paper investigates whether this crucial function of metaphor can also be found when scientific experts communicate with a lay audience of students in the discourse setting of college lectures. For this purpose, we analyze transcriptions of five filmed US-American college lectures in biology, chemistry, psychology and philosophy. Our detailed analysis of authentic language data shows that what Hesse (1966: 157-177) labeled "the explanatory function of metaphor" is indeed systematically exploited for didactic purposes by the professors when communicating scientific concepts to their students. Additionally, our examination also points out that in this educational setting, the explanatory function of metaphor sometimes merges with the heuristic function of metaphor, particularly when students engage in 'creative' discovery in their learning process. Last but not least, although we demonstrate that metaphor has the power to further the students' understanding of the scientific concepts at hand, our analysis also reveals that some metaphor use by the professors might also lead to misconceptions of the respective topics.

Keywords: metaphor and science teaching; explanatory function of metaphor; heuristic function of metaphor; deliberate metaphor; metaphor in college lectures; transcripts.

1. *Introduction*

In her seminal work *Models and Analogies in Science*, published almost half a century ago, Mary Hesse undertakes nothing more and nothing less than the rehabilitation of the value of analogies in science. She distinguishes between positive, negative and neutral analogies. In a positive analogy some properties or aspects of any given analogical model (e.g., the *billiard ball* model for gases) are positively established mappings for a scientific target domain. In a negative analogy properties are clearly established as not applicable. In neutral analogies the possibility of mapping properties from source to target is undetermined. Thus, neutral analogies carry the most interest for the philosopher of

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science, as they hold the potential of making new predictions (Hesse 1966: 8), which is an essential characteristic of scientific explanation. Especially in the last chapter of her book, “The explanatory function of metaphor”, Hesse focuses on the linguistic aspects of this process, expounding how metaphor enables explanations in science to be predictive. In her view, metaphor has such powers by transferring features of a familiar domain (what she calls *secondary system*) as explanans to the scientific domain in question as explanandum (in Hesse’s words the *primary system*), without us knowing the complete extensions of this comparison yet (Hesse 1966: 162-163). The ability to try out implied comparisons or mappings between the two domains that the metaphor sets up is exactly what allows scientists to be predictive in their metaphoric explanations (Hesse 1966: 162-177). Thus, Hesse points out an important function of metaphor in scientific theorizing – the explanatory function of metaphor in scientific models.

While studying the explanatory power of analogies or metaphorical models[1], Mary Hesse was primarily concerned with scientific progress, or “theories in the process of growth” (1966: 10). Thus, the explanatory value of some untried and therefore still neutral analogy lay in its *heuristic* function (cf. Jäkel 2003: 35-36). A prototypical example is described by another prominent philosopher of science: In *The Structure of Scientific Revolutions* (1962), Thomas S. Kuhn relates how the now conventional but then still new conceptualization of electricity as a *fluid* led some Dutch electricians in the early eighteenth century to the creative extension that this fluid could perhaps also be *bottled* in some *container*: The result was the invention of the Leyden jar, the theoretical account of which by Benjamin Franklin led to the first full-fledged paradigm for electricity (Kuhn 1962: 17; 61-62).

Without doubt, the heuristic function of successful models like this is quite impressive. We believe, however, that Mary Hesse’s approach can also be extended to another application of the explanatory power of analogies or metaphorical models in science, and that is in the shape of their *didactic* function. The view that metaphor and analogy are not only key features of theorizing amongst scientists, but are also important tools in teaching scientific ideas and models to a lay audience of students, has been pointed out by various researchers. To name but a few, Mayer (1993: 572) emphasizes that analogies foster learning processes and Justi & Gilbert (2006) argue that analogies are powerful tools for understanding new domains. In both scientific discovery and

[1] In this context, *analogy* and *metaphorical model* can be found in near synonymous use. If differentiation is intended, we will use the term *analogy* to focus on the cross-domain mapping, and *metaphorical model* to highlight its linguistic elaboration. In our account, these are deeply interrelated, representing the proverbial two sides of the same coin.

teaching science contexts, the role of metaphor is assumed to have something of central importance in common: the function of bringing about cognitive change during explanations of scientific phenomena.

While Hesse was concerned with scientists communicating with fellow scientists, the speakers of our data are scientific experts communicating with a lay audience of students. In this paper, we will investigate to what extent Hesse's findings regarding the different functions of analogies and metaphors can be transferred from her setting of scientific progress to our setting of science pedagogy. Throughout our analyses, we will demonstrate how college professors systematically exploit the explanatory function of metaphor for didactic purposes. Moreover, we will point out that in the context of science teaching, the heuristic and the explanatory function sometimes merge, for instance when students are encouraged to engage in 'creative' discovery in their learning process. Let us exemplify the didactic function of metaphors in teaching contexts with an authentic piece of discourse from a German school context (translated into English):

The physics teacher in eighth grade, in the process of explaining refraction, tells her class: "Imagine the beam of light as *a car*". (Longer pause, in which she draws on the blackboard something like figure 1, but without the second arrow). "It moves from an even road onto a boggy field". (Pause, in which she points at her sketch). "And now ask yourselves: What is going to happen to the wheels?" (Longer Pause, until she adds the second arrow to the sketch).

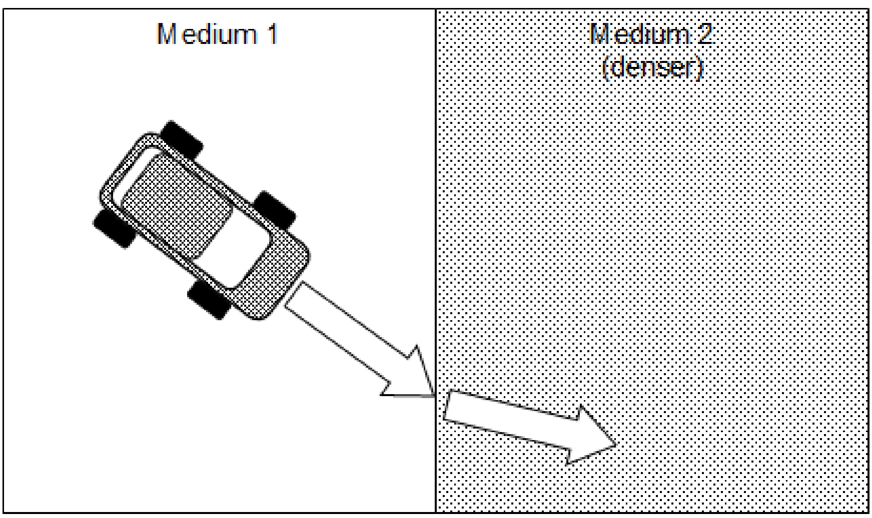

Figure 1: The car model of the light beam

During the teacher's pausing, many if not most pupils will have come to the insight that the car will be making a slight turn to its left, as the left front wheel will meet the denser medium a moment before the right wheel, and therefore be slowed down a bit. This insight, provoked by the very concrete and familiar car model, may even contradict intuitive judgments uttered before by the pupils as to how a light beam would behave when changing from one medium (e.g., air) into a denser medium (e.g., water), which tend to be erroneous. The insight based on the car analogy, though, is exactly what the teacher was aiming to induce in her pupils; and she achieved this by way of her "metaphoric redescription of the domain of the explanandum" (Hesse 1966: 157).

Apart from targeting an audience different from Hesse's (1966), our research is also based on a slightly different theoretical framework. While she loosely adopted the *Interaction View* on metaphor, proposed by Black in 1954, we apply the *Cognitive Metaphor Theory*, which goes back to Lakoff and Johnson in 1980, in our analysis. Although these two views on metaphor differ in some respects, they both share the assumption that there is a metaphorical transference from a more familiar domain to a domain we know less about. Since this seems to be the most important characteristic of metaphor in Hesse's approach as well as in our analysis of science teaching contexts, we will not further elaborate on the differences of these two distinct theories of metaphor here (for a comprehensive discussion see Jäkel 2003: 93-100). Instead, we will focus on the similarities in order to illustrate that it is indeed the explanatory function of metaphor that is crucial – not only for scientific reasoning amongst scientists, but also for teaching scientific concepts.[2]

In the next section, we will therefore give a condensed overview of the main tenets of the *Cognitive Metaphor Theory* (CMT) and its recent additions by Steen (2008; 2011). Following a short outline of the corpus material and method used in our research in section 3, we will in the main section 4 present and discuss various instances of metaphorical models used in teaching science. The paper will be brought to a close with a short summary and conclusion (section 5).

[2] The general cognitive role and function of metaphor, which has been at the core of the Cognitive Metaphor Theory (cf. section 2) right from its start (Lakoff & Johnson 1980), has several manifestations. To avoid misunderstandings, it may need to be said that for us as cognitive linguists, neither the explanatory function (cf. Jäkel 2003: 31-36), nor its even more specialized subcases of heuristic and didactic functions of metaphor, contradict its general functional characterization for human cognition: namely as enabling, organizing, and creatively extending human understanding.

2. *Cognitive Metaphor Theory*

The Cognitive Metaphor Theory (CMT) claims that metaphors are not only a fundamental part of our everyday language (as opposed to being merely a device of poetry or rhetoric), but also underlying principles of our conceptual organization (Lakoff and Johnson 1980: 3). Lakoff and Johnson claim that the "essence of metaphor is understanding and experiencing one kind of thing in terms of another" (1980: 5). It is typically the case that conceptual domains which are more abstract and less clearly delineated need to be comprehended in terms of those domains that are more basic, familiar or concrete (Lakoff and Johnson 1980: 177; Lakoff 1993: 244-246). In this view, metaphor is understood as a set of cross-domain mappings between the more familiar or more concrete domain (*source domain*) and the less familiar or more abstract domain (*target domain*) and thus allows us to understand a less known concept by resorting to conceptual domains that are better known (Lakoff 1993: 244-246; for a comprehensive discussion of this unidirectionality hypothesis see Jäkel 2003: 55-62). As science is mostly concerned with unfamiliar and abstract domains, metaphor plays a central role in scientific thought (cf. Gentner & Jeziorski 1993: 447). Popular examples of elaborate mappings between two domains in science include the abovementioned analogy of *electricity* (target domain) as a *fluid* (source domain).

Most proponents of CMT also assume that metaphor is mostly conventional, unconscious and automatic (Lakoff 1993: 244-246) – we usually do not realize that we use metaphors or are engaged in cross-domain mappings in our comprehension or production of metaphorical expressions. Over the past decades, there has been much dispute about whether or not we perform a cross-domain mapping each time we encounter a conventional metaphor (see for example Bowdle & Gentner 2005, or the overview on metaphor processing theories provided by Gibbs & Colston 2012). Steen (2008) coined the expression 'the paradox of metaphor' to describe the view that a lot of metaphors in language (i.e., words which have a contextual meaning that is distinct from their more basic meaning, but can be understood by comparing the two) may actually not be metaphors in thought, because they do not require the active performance of a cross-domain mapping for comprehension. Instead of via such cross-domain mapping, most conventional metaphors may be processed by categorization or lexical disambiguation (cf. Steen 2008; 2011). This 'paradox of metaphor' has led some scholars of CMT to a reclassification of metaphor. Steen (2008; 2011), in particular, proposes a model of metaphor in which he differentiates between metaphors that probably do not involve cross-domain mappings and those that do, marking the latter as *deliberate metaphors*. This kind of metaphor is assumed to be "expressly meant to change the addressee's perspective on the referent or topic that is the target of the metaphor, by making the addressee look at it from a different conceptual domain or space, which functions as a conceptual source" (Steen 2008: 222). Since this kind of metaphor is meant to bring about cognitive change on the part of the addressee, it seems particularly valuable in teaching science contexts, just like in the initial example of the *light beam* as a *car*. In our analysis, we will present examples of such contexts and discuss how (deliberate) metaphor facilitates understanding scientific phenomena by providing a different cognitive angle on the respective topics.

3. *Corpus data and method*

The linguistic data on which the following analyses will be based come from Anke Beger's current PhD research. The project under the title of "Linguistic Analysis of Expert-Lay-Communication in Different Discourse Settings and Domains: The Transfer of Knowledge in Higher Education and the Role of Metaphor" aims at analyzing academic discourse and the role of metaphor in the communication of knowledge. The investigation is exploratory and involves the analysis of 27 lectures filmed at a US-American college in the following subjects: Biology, Chemistry, Psychology, and Philosophy. The analysis combines the Cognitive Metaphor Theory and Discourse Analysis. Notice that in the following discussion of examples, we are extending the category of *science* to a broader approach which includes 'humanities' subjects like psychology and philosophy.

Our analysis here will be based on one lecture each from biology, chemistry, and philosophy, plus two lectures from psychology. The video data of these five lectures was first transcribed and then analyzed for metaphor use. The transcription rendered a corpus containing authentic discourse data of roughly 47,000 words. Metaphor identification was carried out on the basis of the Metaphor Identification Procedure (Pragglejaz Group 2007) and its more recent elaboration (Steen *et al.* 2010). In the case of the psychology lectures, the identification procedure was carried out throughout the entire lectures. In the rest of the data, only excerpts (including those that will be discussed here) were subjected to detailed metaphor identification. For our present purposes it is not necessary to identify each and every possible metaphor in the data, but to make sure that what we identify as metaphor is indeed classified as such.

For our discussion of examples of deliberate metaphor use, we will provide crucial excerpts of our data. As to notational conventions used in these excerpts, only those metaphors that are of importance for our present analysis are highlighted, using a combination of italics and bold print. Since we are primarily concerned with *deliberate metaphors*, the occasional linguistic signals which provide evidence for deliberateness are underlined. As our examples of deliberate metaphors as a teaching device occur in particular real-life contexts, we have to take these contexts into account when examining the metaphor use. Thus, we will also include aspects of discourse analysis in our discussion of the examples. Therefore relevant (non-metaphoric) expressions are highlighted using bold print (without italics). The fact that we have real-life video material enables us to carry out such a multi-faceted analysis, considering different factors of text and context. These advantages of analyzing authentic language use compensate for the small drawback that relying on recording devices brings with it: the loss of some data due to parts that are inaudible. This rare problem usually only involves individual words, which are marked in the excerpts by a question mark in brackets. Our discussion of the examples always involves an analysis of language as well as making inferences about the conceptual level, based on the language use. In order to mark this difference, we follow the usual cognitive linguistic convention of using small capitals for conceptual units.

4. *Discussion of examples*

4.1. Molecular biology

The first example is taken from a class in molecular biology. The topic of this particular lecture is the activation of the DNA transcription process. In the excerpt below (example 1), the professor is explaining the structure of transcription factors.

(1) So you could actually make sort of ***Frankenstein*** hybrid transcription factors with cloning techniques, um, where you sort of, let's say you had several different activators, you could sort of **mix and match** DNA binding domains and activation domains and, um, and sort of make new transcription factors (…).

Transcription factors control the DNA transcription process. They do that by binding to specific sequences of the DNA and activating the transcription process, which is accomplished by also binding to other proteins. This means that the structure of transcription factors contains at least two domains, one which is responsible for DNA binding and one responsible for activation. What the students do not seem to know is that those domains work independently and can be separated as well as reassembled. The professor tries to communicate this idea by using the metaphor *Frankenstein hybrid transcription factors.*

He calls the transcription factors that result from separating and reassembling domains of different transcription factors *Frankenstein hybrid transcription factors*. Thereby the professor sets up a comparison between what a biologist can do to transcription factors and what the character Frankenstein in Mary Shelley's novel does to human body parts. Instead of simply saying that the domains of the transcription factors can be separated and reassembled, the professor chooses to compare this biological process to the work of Frankenstein. This allows the students to think of biological processes that are invisible to the human eye, and hence more difficult to comprehend, in terms of something that is probably familiar to them (the basic plot of the novel *Frankenstein*). Since Frankenstein reassembles human body parts to design a new creature, this process is easier to imagine and understand. We are much more familiar with our own body than with parts of submicroscopic proteins. Thus, this comparison might help the students to understand the processes involved in creating new transcription factors.

However, the use of this particular metaphor might also suggest that this biological process is unorthodox and results in something unwanted and dangerous. After all, our knowledge of the novel includes that Frankenstein's experiment goes different from what he imagined and results in the creation of a monster. Yet, the professor does not seem to wish to convey this view, because over the course of the lecture, the creation of new transcription factors is explained as something useful and positive. This example therefore demonstrates some of the advantages and pitfalls of using metaphors in teaching science. On the one hand, the *Frankenstein* metaphor probably helps students to understand the biological processes the professor is trying to explain. On the other hand, this particular metaphor might lead to a certain evaluation – due to the negative connotation the word *Frankenstein* carries – of the processes that is not intended.

4.2. Evolutionary psychology

Apart from leading to wrong inferences in terms of connotation, a problematic use of metaphors may even result in a wrong concept of the topic at hand. This may have happened in example (2), which we will analyze in the following discussion. This example of deliberate metaphor use is taken from a class in evolutionary psychology. The session deals with the concept of *sperm competition*. The idea of sperm competition in human beings arises from the fact that two or more different males are able to try to fertilize the egg of a single female, for example by mating in close temporal proximity. Throughout the lecture, the professor provides evidence from different studies which suggest that males have evolved in ways that are adaptive to sperm competition, which in turn supports the idea that sperm competition indeed exists. In example (2a) below, the professor relates laboratory research on the concept of *semen displacement*, which is assumed to be one of the adaptive mechanisms enabling males to succeed in sperm competition.

(2)

(a) There are even these labs where they've got these latex vaginas and these you know perfectly sculptured penises and they have these little thrusting machines where they can adjust the angle and the force and the speed. And then they've got this liquid substance that perfectly simulates semen and they find that penises are perfectly designed for displacing the semen of other men. It's like this ***pile-driver***: it **goes in** and just kind of ***shoots*** **it out to the side** and you do find more vigorous penile thrusting following a period of absence from one's partner.

The professor starts out by describing the setting of a laboratory experiment that investigates the human penis as a semen displacement device. In the study the professor refers to, researchers have used artificial penises and vaginas in order to test if the human penis is in fact able to displace semen that was left in the vagina by a different male. The study also investigates which parts and mechanisms of the penis are crucial in the displacement process by manipulating different features of the artificial penises (Gallup *et al.* 2003, reported in Goetz & Shackelford 2006)[3]. Once the professor has summarized the setup of the laboratory study, he states the conclusion of the experiment: Penises are perfectly designed for semen displacement. He then uses a deliberate metaphor that compares the penis to a *pile driver* in order to explain in how far the design of the penis helps displacing other men's sperm. The deliberate metaphor has the form of a simile and thus sets up a direct comparison, forcing the students to consider the target domain (PENIS MECHANISMS) from the perspective of the source domain (PILE DRIVER). The professor proceeds by clarifying which aspects of PILE DRIVER are supposed to be mapped onto the target domain. Apparently, the two domains share that they "go in" (into the ground and into the vagina, respectively) and shoot "it" out to the side. The "it" is supposedly the soil in the source domain and the semen left behind in the vagina by other men in the target domain. Although the target domain in itself is quite concrete and the process of vaginal penetration is probably fa-

[3] According to the professor himself (personal communication), what he explains in the excerpt of example (2a) is based on an edited volume by Platek and Shackelford (2006), in which two different chapters (one by two of the initial researchers, Gallup and Burch, and the other one by Goetz and Shackelford) describe or refer to the original study by Gallup *et al.* (2003).

miliar to most students, the idea that the form of the penis and the manner of penetration is supposed to displace possible left-over sperm from rival males is presumably unfamiliar to the students. We would expect that their concepts of penis and penetration still relate to a folk idea about (the purpose of) sex that do not include expert concepts of adaptive mechanisms to secure maximal reproductive success (even in the case of multiple mating partners of females). Thus, the metaphor of the pile driver that supposedly *shoots soil out of the ground* while ramming a pile into it seems to be a helpful comparison. In both cases, something new is supposed to take up space and displace something else that is already inside. This may help the students to consider the penis as more than a device to fertilize the egg and thus result in a cognitive change in regard to their concept of the function of the penis.

However, upon closer examination, the metaphor has several problems in furthering the students' understanding of the target domain. First of all, the source domain does not exhibit the characteristics ascribed to it by the professor. When a pile driver drives poles into the ground, the soil is usually not visibly displaced. The device does not normally "shoot" anything "out to the side". Typically, the poles slide into the ground quite slowly and it cannot be seen where the soil previously taking up the space ends up. Despite this incorrect portrayal of the source domain, the metaphor may still be understood and produce the intended change in perspective, because the professor spells out the intended mapping. Even though the aspects he wants the students to map onto the target domain are not present in the source domain, the explanation that immediately follows the metaphor might further the students' understanding of the topic. Yet, another – more important – problem is that it is precisely the professor's explanation that communicates a wrong understanding of how a penis actually performs the semen displacement. The penis does not "shoot" anything "out to the side" either. According to the study the professor is referring to, the laboratory experiments show that "the frenulum of the coronal ridge makes possible semen displacement by allowing semen to flow back under the penis alongside the frenulum and collect on the anterior of the shaft behind the coronal ridge" (Goetz & Shackelford 2006: 176-177). This means that due to the thrusting, the semen basically gets "scooped up" by the penis and is pulled out of the vagina rather than "shot out". It may be the case that the professor's misconception of the manner in which the penis can achieve the goal of semen displacement stems from the fact that "more vigorous penile thrusting", as the professor calls it, is indeed necessary. As Gallup *et al.* (2003: 281) specify, the more vigorous thrusting has to involve deeper thrusting, most of all. However, the idea that more force is involved might have led the professor to the erroneous assumption that the semen is displaced in a sudden and forceful manner, as implied by the metaphor "shoot out". The aspect of great force is implied by "more vigorous thrusting", which was indeed reported to be often present in sexual encounters when the males faced a situation that may have involved sperm competition. This finding is the result of a survey, also carried out by Gallup *et al.* (2003), which is reported in the same chapter of the edited volume the professor refers to (Goetz & Shackelford 2006: 177), and might have contributed to the misconception on the professor's side. This might also explain the choice of the metaphor's source domain PILE DRIVER. The hammer of a pile driver does exhibit great vigor when driving the piles into the ground. Therefore, the metaphor does capture some aspect of the manner associated with the penis when displacing semen. Since both *pile driver* and *shoot out* imply great force, this aspect of penile thrusting (in certain circumstances) is then, in all probability, understood by the students. However, the deliberate metaphor *pile driver* and the subsequent metaphorical elaboration using the phrase *shoot out* fail to communicate the central and crucial mechanisms of the penis that, according to Gallup *et al.* (2003), enable males to displace the semen of potential rivals.

Intriguingly, the professor does not end his explanation of the semen displacement theory with the metaphors illustrated in example (2a). He continues the explanation by rephrasing what he has said before, as shown in example (2b):

(b) **In other words**, if you're away from your partner for a while, when you come back, in your sex there's much more penetration than usual, so it's almost as if…**ok I know there's a risk here of some other junk being in here and we gotta take care of that**. None of this is conscious except at my house [students are laughing].

The formulation "in other words" indicates that the professor feels the need to rephrase his previous explanation. Hence, he does not seem to assume that his deliberate metaphor use was sufficient for teaching this particular scientific concept. At the same time, the vagueness of the professor's description provided in example (2b) may indicate that the professor's main aim is not necessarily that the students understand the exact fashion in which the penis performs semen displacement. The expression "more penetration" might refer to a number of manners of penetration – speed, vigor, duration, etc. – and the phrase "take care of that" is also not specifying the way in which this is supposed to happen. However, the professor uses another useful teaching device in example (2b): humor. Beginning with "ok I know…", the professor jokingly voices the unconscious thoughts or intuitions a man may have after being away from his partner for a period of time. He then warns against a possible misunderstanding of the action as being consciously performed, by adding a joke about his personal sex life. The laughter of the students, apart from bringing some comic relief, may also indicate that they have understood the professor's point. This additional explanation of the idea of semen displacement suggests that the professor's focus may not so much be on the specific manner in which the displacement is performed. Rather, the professor seems to intend to make the students understand the overall theory of semen displacement, thereby transforming the students' lay perspective on the purpose of mating into a more complex, academically informed concept. By using humor and voicing assumed evolutionary-determined intuitions of males in his second part of the explanation (example 2b), the professor creates a scenario which is probably easy to understand for all students, whereas the source domain PILE DRIVER in his previous deliberate metaphor may not even have been known to everyone. This, in combination with humor – possibly to attract the students' attention – may facilitate a cognitive change on the side of the students. They may alter their concept of mating as a reproductive process to the concept of mating as a reproductive process that includes diminishing the possibility of other men's sperm being more successful with the same woman. In turn, this reformed concept of mating supports understanding the unfamiliar theory of sperm competition as the bigger picture the professor is trying to communicate.

4.3. Nuclear chemistry

The next excerpts in example (3) are taken from general chemistry, an introductory chemistry class. The topic of the lecture is nuclear chemistry. The professor is concerned with explaining the behavior of subatomic particles and the nucleus in order to make the students understand what kinds of radioactivity exist and how they happen. Interestingly, the professor often personifies the subatomic particles as well as the nucleus in his explanations, which is illustrated by example (3). In the following analysis, we will consider the use of personification in different parts of the lecture and argue that the accumulation of those metaphors suggests a deliberate use of metaphor. We will start with examples (3a) to (3c), in which the professor tries to explain one of the most common radioactive particles, the beta particle, which is essentially an electron (or a positron). A student is confused, because in his understanding, in the example they are discussing, a proton is needed to change from Iodine to Xenon, and not, as the professor states, an electron. In his explanation, the professor clarifies that they have a neutron, which is a composite of a proton and an electron. By becoming a proton, the neutron loses the electron, which is the beta particle. This process is described metaphorically by the professor in (3a) and again in (3c), after a student asks for further clarification (3b).

(3)

(a) Prof: And so, we've got an actual nuclear particle, falling apart. And when the neutron falls apart, ***spits out*** an electron, it becomes a proton. And that's how we can go from Iodine 53 protons to Xenon 54 protons and ***spit out*** the electron. It's because one of the nucleons has changed the ***identity*** […].

(b) Student: So, the Iodine is losing a neutron, but it ***kicks off*** an electron?

(c) Prof: […] It's just that one of the neutrons becomes a proton. And in that process, you know, ***pukes out*** an electron.

In example (3a), the professor's first use of *spit out* suggests that he compares the behavior of a neutron to that of a living being. His second use of the phrase is less clear, since it refers to "we", suggesting that he and the students spit out the electron in the process of doing an equation (on the board). However, as we will see in the following, the professor's usual pattern is to ascribe human features to the subatomic particles and the nucleus. He concludes his explanation of where the electron comes from by ascribing an identity to a nucleon, something that is usually exclusively ascribed to human beings. This demonstrates that he is not only personifying neutrons, but different subatomic particles. Describing subatomic particles in terms of human characteristics, and their behavior in terms of human behavior, allows the students to draw on a familiar domain when trying to understand ideas and processes of chemistry that are not at all perceivable with any of our senses. In fact, the nature of subatomic particles is still being examined by scientists. One of the major problems of investigating those particles is actually that they can barely be made perceivable.

Interestingly, when the student checks if he has understood the concept correctly in (3b), he seems to adopt the professor's use of personification. This may indicate that the student has adopted this view on subatomic particles and uses the metaphor in order to reason about the topic at hand. Furthermore, he does not simply repeat the metaphorical expression that the professor has used before verbatim, but comes up with his own linguistic metaphor *kick off*. The metaphorical expressions *kick off* and *spit out* not only share the source domain PERSON, but also the underlying image schema of actively getting something away from the body. Even though the professor's metaphor suggests a movement from inside the body, while the student's metaphor indicates motion starting at the surface of the body, the core aspect "movement away from the body" is present in both metaphors. Although the student uses a metaphor that supports the important aspects of the target domain, his understanding of the process the professor is trying to explain still seems to be unsatisfactory. Hence, the professor elaborates on the issue (3c), reminding the students that the number of nucleons does not change from Iodine to Xenon. He then concludes his elaboration by more or less repeating his statement from (3a). As we can see in (3c), the professor restates that the process of becoming a proton involves that the neutron loses an electron. Ridding itself of the electron is again described metaphorically, this time using the phrase *puke out*, which also has PERSON as its source domain. Additionally, the metaphor is almost a near-synonym to the professor's original metaphorical expression *spit out*, and it is also based on the image schema mentioned above. It seems to be the case that using metaphors that draw on bodily experiences like spitting and puking are intended to help the students to better grasp the chemical processes at hand, but as we have seen in the student's reaction in (3b), the understanding might only be partial.

So far, we have just considered one short excerpt from the lecture and looked at a few instances of metaphors used by the professor that happen to share the source domain PERSON. This short excerpt alone does not necessarily prove that the professor is deliberately using metaphor, or more particularly, personification, in order to facilitate the understanding of subatomic particles and the nucleus. However, as the class proceeds, we find more instances of this explanation strategy. This is illustrated in examples (3d) and (3e) below. Example (3d) occurs after the professor introduced a new particle, the positron, in order to explain positron annihilation, which is another kind of radioactivity.

(d) Every positron that's ever ***born*** has one fake in store. One fake. It will have this happen to it: It will ***find*** that much more common version of itself – an electron. It will ***find*** it.

In (3d), apart from being born, the aspect of intentional acting is mapped from the source domain PERSON onto positrons. This metaphor probably helps to understand why positron annihilation is an inevitable process once a positron is emitted. If we did not think of positrons as intentionally searching for an electron, we might think that the two particles do not necessarily have to collide with each other in cases of positron emission. However, subsequent questions from students indicate that this metaphor seems to have led to the assumption that positron annihilation is a very common process. Thus, the professor has to clarify that positron emission is rather uncommon to begin with. As example (3e) illustrates, he does so by using personification again.

(e) You have to have an ***unhappy*** nucleus in its whole in order for something like this to happen. (…) And they have to be, they have to be unstable in the whole nucleus for it to want to ***spit*** something ***out***. And the thing that it ***spits out*** is going to be to some extent dependent upon what the source of its problem is.

In order for positron emission to happen, many different aspects of a nucleon have to be unstable. Since this seems to be a complex phenomenon, the metaphor *unhappy* is probably quite suitable to help the students understand that a lot of things need to come together for positron emission to take place. From our experience as human beings, we know that usually several things have to happen to make us unhappy. A single aspect going wrong in our lives does not normally lead to unhappiness. After this new instance of personification, which again captures a different aspect of the source domain PERSON in order to explain an aspect of nucleons, the professor proceeds by repeating the metaphor *spit out*. However, this time, it is used to further describe the nucleon and not, as we have seen in (3a) and (3c), a subatomic particle.

Later on in the lecture, the professor again has to clarify (3h) a concept after a student signals that he has not yet understood it (3g). In the excerpt below, the student struggles with comprehending the concept of K-capture, yet another kind of radioactivity.

(f) Prof: Yes, that's right. So, when you do this, you gonna take carbon and you gonna make it into boron.
(g) Student: How does the electron get to the (?) ?
(h) Prof: It's probably (?), I mean, how do you know that a particular electron is ***Jake***, the electron that you'***ve been friends with*** forever? I mean, once the electron, you know, sort of gets into the range where it's (?) the other electrons, then its ***identity*** is very uncertain.

In this excerpt, the professor tries to convey the idea that it is not possible to correctly identify and trace a particular electron once it is in a certain atomic region. In order to do so, he compares an electron with a human being. Being able to trace and identify a particular electron is seen as being friends with another person. If we are friends with someone, we are usually able to identify and detect them – and to follow their movement – in a group of people, whereas we might not be able to identify anybody else in an amorphous group of people, or notice their movement.

In the final sentence of (3h), the metaphor *identity*, which already came up in our analysis of example (3a) above, enforces the professor's use of personification for subatomic particles, which we have already witnessed in the previous parts of example (3). However, this time, the professor does not simply draw on aspects of human beings in general. Giving the electron a name and calling it a *friend* is a more individual specification of this metaphor. Whereas in the preceding parts of the lecture, the professor used general aspects of human beings in his metaphors (e.g., being *born*, the ability to *spit* and *puke* something *out*), he is now referring to a specific person that he calls *Jake*. In addition to being more individual than the previous metaphors, this metaphor probably also draws special attention to the source domain by bringing in humor. It seems to be a comical note that the professor is not only asking the students to think of an electron as a long-lasting friend, but that he is also giving it a specific name, *Jake*.

The metaphors discussed in the discourse reported as example (3) illustrate how the professor seems to be systematically employing personification in order to further the students' understanding of subatomic particles and the nucleon. In each case, the metaphors focus on different aspects of human beings, for example intentional action (3d), having emotions (3e), or friendship (3h). Yet, all of these metaphors share the same source domain HUMAN BEING, which, since we all are human beings, is so familiar to us that it has great potential in aiding our reasoning processes about less familiar and more abstract domains (in this case, subatomic particles and the nucleon). The fact that the professor uses various linguistic metaphors instantiating the same source domain, combined with the observance that he uses this coherent set of personification metaphors throughout his lecture – and at points where problems in the students' understanding arise that require clarification – indicates that he uses those metaphors deliberately. The situations in which these personifications occur also suggest that his purpose in using metaphors is to clarify problematic issues of the topic at hand and thus to further the students' understanding. Particularly the dialogic sequence (3a) and (3b) shows that students are indeed able to adopt the alternative perspective on the topic offered by the metaphors and to reason from that point of view.

4.4. Social psychology

Another interesting instance of deliberate metaphor use takes place in a social psychology class. The lecture is about aggression and the professor explains different theories of aggression. The professor has already talked for several minutes about Freud's idea of *Eros*, the human sex drive. In the excerpt in example (4), he describes what Freud considered to be the instinct opposing *Eros*: *Thanatos*.

(4) He [Freud] called this instinct Thanatos. And sometimes this is called the death instinct. And so, he began to change his model of human nature to one that was kind of a ***battle*** between these different ***competing*** instincts – a ***battle*** for which type of energy

would ***win out***. To use Star Wars terminology: This would be our ***dark side***. This is the part of us that is aimed toward destruction.

As we can see in example (4), the professor explains Freud's model of the human nature by using several metaphors that share the source domain WAR, namely *battle* (twice)*, competing*, and *win out*. This accumulation of coherent metaphorical expressions in one sentence already suggests that the professor is using these metaphors deliberately (cf. Krennmayr 2011: 154). Instincts, which are part of our psyche and hence not a physical phenomenon, are not perceivable with our senses. Comparing the opposing dynamics of two instincts to two opponents in a battle allows the students to understand the topic at hand by drawing on a conceptual domain they are familiar with. However, once he has set up the WAR framework in order to explain the dynamics of the two instincts, the professor introduces a new comparison to elaborate on the nature of *Thanatos*. He compares the death instinct to the *dark side* in the movie series "Star Wars". Linguistically, this comparison is made explicit by using the phrase "to use… terminology". Thus, he explicitly instructs the students to consider the topic at hand, *Thanatos*, from the perspective of "Star Wars", which makes this an exemplar case of deliberate metaphor. Intriguingly, the dark side of the force in "Star Wars" is a very abstract and complex concept in itself. It basically represents those aspects of a mystical, invisible energy that permeates the "Star Wars" galaxy, which are considered to be evil and destructive by the "Star Wars" characters portrayed as "good". It is probably precisely this ability to mentally assign a certain group of characters (the antagonists) to the dark side, which makes the source domain less abstract than the target domain. However, throughout the movies, the use of the *dark side* seems to reflect exactly what *Thanatos* and *Eros* seem to be: competing internal forces that lead us to "evil" or "good" behavior. On the one hand, a rich knowledge of the "Star Wars" movies probably allows the students to map a wide set of aspects from the source domain DARK SIDE to the target domain THANATOS. On the other hand, the exact mappings highly depend on the understanding of the source domain, which is not only rather difficult in this case (as opposed to the personification in the chemistry excerpt above, for example) but probably also very individual. Yet, a crude understanding of the basic plot should at least allow the students to assign the "bad guys" to the dark side, which facilitates a basic understanding of the concept THANATOS. However, not all students may be familiar with "Star Wars". These problems might have led the professor to clarify that Thanatos is the instinct which is aimed toward destruction in the last sentence of example (4).

4.5. Philosophy of the mind

Our next example of deliberate metaphor as a teaching device comes from a lecture in the philosophy of the mind. In this lecture, the professor is mainly concerned with two texts: an article by John Searle (1981) which argues against the strong view of Artificial Intelligence that a certain kind of software on a computer could create some conscious being, and the response to that article by Douglas Hofstadter (1981). In his argument, Searle says that if we assume the presence of a mind in computers on the grounds of the system receiving input, performing processes over formally defined elements and generating output, we could also think of the stomach as having a mind. However, since we would not think of the stomach as having a mind, we need a different definition of what a mind is – and not just think of it as performing computational processes. This line of argumentation is what the professor is trying to explain to his students in example (5) below.

(5)

(a) Prof: yeah, and you know, the main thing that Searle's doing is, you know, pumping around intuitions, as Dennett calls it, uh, and you know, saying 'look, we can **define the *stomach* in the exact same way that the computationalists define the *brain***.' Right? We don't wanna say that what the stomach is doing is thought or understanding or awareness. <u>Likewise</u>, you know, since the brain is doing exactly the same thing, it's just, you know, slightly – or quite a bit – more complex, uh, it's just doing the exact same sorts of things and so, you know, **if we don't call the *stomach* a *mind*, therefore we shouldn't call the *brain* a *mind***. Yeah, Anna?

(b) Student: I don't really see how **food** is the same as **data** –

(c) Prof: Uhu.

(d) Student: – like, uh, isn't ***food*** – <u>wouldn't that be more comparable</u> for the ***machine being charged*** or something? (…)

In (5a), the professor summarizes Searle's comparison between the brain and the stomach in order to argue that the brain is not a mind. He starts by rephrasing Searle's assumption that the stomach could be defined in the same way computationalists define the brain, which sets up a comparison between the stomach and the brain. He then establishes that we would not ascribe thought, understanding or awareness to a stomach. In his analogy between the stomach and the brain, this leads to the inference that we should not assign these aspects to the brain either. This analogical reasoning, comparing the stomach to the brain, is signaled by the word *likewise*.

Within that reasoning, the professor also states what the stomach and the brain supposedly have in common, which is what led to the comparison in the first place. The comparison is based on the idea that both mind and brain are "doing exactly the same thing", which the professor has explained before in more detail: Both receive input, which then undergoes formally defined processes, and results in output. In this analogy, the stomach's input *food* is mapped onto *data*, the rather abstract 'input' a brain receives. It is exactly this mapping that a student immediately contests. In addition to challenging the view that food can be seen as the stomach's data (5b), she also offers a different target for the metaphorical mapping that she finds more convincing (5d). In her view, food would not be the data of a machine, but something (probably some power source) that charges a machine.[4] Again, the comparison is linguistically marked by the student's phrase "wouldn't that be more comparable". Her view is probably based on the concepts that *data* is usually some kind of information, whereas *food* is something that provides the body with energy. Hence, the student does not seem to see convincing parallels between *food* and *data* regarding their respective nature and/or function and rejects the comparison. Her rejection as well as her alternative comparison demonstrates that she has consciously thought about the analogy in order to reason about the topic at hand. We have already seen a similar case in example (3b), where a student used the professor's metaphor in a linguistically slightly different version in order to think about subatomic particles in chemistry. However, this time the student not only uses the professor's analogy in order to follow the professor's reasoning, but also to question the appropriateness of this reasoning.

5. *Summary and conclusion*

Our detailed, corpus-based analyses of real-life examples of metaphorical models employed by US-American college professors in their academic teaching were meant to demonstrate one important finding: There is indeed the systematic exploitation of what Mary Hesse (1966: 157-177) labeled "the explanatory function of metaphor" for didactic purposes. In all the discourse examples discussed, there was substantial evidence indicating the *deliberate* use of particular metaphors, both linguistic and conceptual, with the didactic intention of inviting students to conceptually reframe the target domain in question by activating mappings from the source domain.

[4] The underlying conceptual metaphor which is criticized by Searle and serves as the basis of the comparison illustrated in example (5) is THE BRAIN IS A COMPUTER. Hence, the student refers to the brain as a machine.

The linguistic signals that can be regarded as providing evidence for deliberateness in the professors' metaphor use range from the "*like*" particle in example (2) or the "*likewise*" in (5), which signal a direct comparison between the two domains in question, to the explicit announcement of a new source domain perspective by way of the phrase "*to use Star Wars terminology*" in example (4). Even the longer phrase "*wouldn't that be more comparable*" in example (5), though coming from a student, has a similar metalinguistic quality. Eventually, it is the accumulation of a coherent set of metaphors in the discourse that in some cases clearly indicates deliberateness (see example 3).

Looking back at her loosely established terminology of *positive*, *negative*, and *neutral* analogies – Hesse (1966: 8) only ascribes these terms to "the Campbellian", one of two opponents in a philosophical dialogue – one might speculate that, while researchers would be well-advised to go for *neutral* analogies as powerful heuristic tools to further scientific progress, teachers should rather be careful to employ metaphorical models for the sake of some *positively* established mappings or analogies. But among other things, the cases discussed above may also indicate that such speculation would probably be based on oversimplified assumptions, as will briefly be explained next.

The potential analogies or mappings of any metaphorical model are manifold. A teacher may have some very particular mappings in mind and regard them as positively established, secure and therefore useful for the didactic purposes at hand. The situation, however, is much more complex. For one thing, the metaphorical source domain in any analogical reasoning will be richer and thus, harder to control than any particular teaching purpose would approve of. For another, the purpose of deliberate metaphor use by a speaker is the activation of some addressees' conceptual system, inviting them to change their perspective and reframe their conceptualization of the target domain. Therefore, we will need to take into account that teachers are dealing with larger numbers of individuals, all equipped with their individual mindsets, which will in all likelihood play a role and affect the understanding – or misunderstanding – of those metaphorical models.

Whereas those personifications used by the chemistry professor in example (3) probably come closest to exemplifying the successful use of metaphors in the sense of *positive analogies*, most of the other examples seemed to include some problems with the applicability of mappings. But how can any professor ever be in full control of the mappings suggested by a metaphorical model? Both the *pile driver* metaphor in example (2) and the *dark side* metaphor in example (4), as well as the *food* analogy in example (5) speak otherwise. Or does a professor need to explicitly pinpoint *negative analogies* in order to prevent potential misunderstandings of a metaphor whose *positive analogies* he wants to exploit? The *Frankenstein* metaphor in example (1) might be a case in point.

The cases we investigated may even suggest that analogies intended to be *positive* could also legitimately be regarded as *neutral.* The students may see the cases we presented as predictive, allowing for some creative 'discovery' in an active learning process. In fact, Mary Hesse herself never intended the distinction between *positive* and *neutral analogies* to be mistaken for a hard and fast one. Discussing "any interesting examples of model-using in science", she states (1966: 162): "For one thing, as long as the model is under active consideration as an ingredient in an explanation, we do not know how far the comparison extends – it is precisely in its extension that the fruitfulness of the model may lie". This may be just as true for didactic purposes of metaphorical models as it is for heuristic purposes.

Apart from also revealing possible problems of using deliberate metaphors in teaching science, however, we demonstrated that it is indeed deliberate metaphor that possibly affords cognitive change and hence is likely to further the students' understanding of the respective scientific concepts. Although it becomes quite evident that the professors' use of deliberate metaphors enables the students to perform a cognitive change in order to understand scientific concepts, the question whether the students will actually reframe their concepts remains open. To find out whether deliberate metaphor use eventually results in greater learning success, more studies investigating and testing the learning outcome would be useful. This might be one interesting direction for future research.

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