On the significance of conceptual metaphors in teaching and learning science – A commentary on three papers of the present special issue

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We are delighted to be invited for this task as our own work on conceptual change (e.g. Duit & Treagust, 2003) so far has not explicitly included ideas of the conceptual metaphor field. In other words, we see this task as a chance to revise and further develop our more "classical" conceptual change views.

Comments on our own research work on the role of analogies and metaphors

The role of analogies and metaphors has played a significant part in our work on teaching and learning science. Reinders Duit's academic study leave at the Science and Mathematics Education Centre (SMEC) of Curtin University in 1988 was the start of that work. Duit (1991) summarized the state of literature on the role of analogies and metaphors in science teaching and learning in a review paper. Analogies were seen as comparisons of structures between two domains based on structural similarities between these domains used to initiate understanding of the key features of a concept to be learned. With regard to metaphors we conceptualized them as analogies with particular emphasis: "*taken as literal*, a metaphorical statement appears to be perversely asserting something to be what it is plainly known not to be. … But such 'absurdity' and 'falsity' are of the essence: in their absence, we would not have a metaphor but merely a literal utterance" (Black, 1993, p. 21). Briefly put, a metaphor in this sense compares entities without doing so explicitly. Metaphors are comparisons where the basis of comparison must be revealed or even created by the addressee of the metaphor. A "good" metaphor always includes some dose of surprise. Clearly, this is a different meaning compared to the conceptual metaphors discussed in the various papers of the present issue. As used in these studies, conceptual metaphors denote linguistic figures of speech based on certain embodied experiences such as the substance metaphor for the energy concept in physics.

We carried out research on the role of analogies and metaphors (in the above "classical" sense) in various studies. We investigated, for instance, the use of analogies by teachers clarifying aspects of science content in ordinary classroom practice (Treagust, Duit, Joslin, & Lindauer, 1992), and the power of using analogies as instructional tools in science classrooms (Treagust, Venville, Harrison, & Dagher, 1996). Research on the role of analogies in guiding students to basic ideas of non-linear systems (Wilbers & Duit, 2006) questioned the classical approach as represented by Gentner (1983), especially her structure mapping idea. It turned out, namely, that it was not the similarities of certain structural features of source and target that initiated students' processes of using the analogy provided: "Students interpret base and target domains in fundamentally different ways. Learning by analogy rests on visual perception. It traces a line of concrete visualization and abstraction by transcending the concrete in a second step. To put it into a nutshell: a student's heuristic analogy is built on mental images rather than propositionally based knowledge" (Wilbers & Duit, 2006, p. 37). This seems to be a figure of thought whose significance is also highlighted by the conceptual metaphor approach discussed in the present volume.

Metaphors have been used as powerful tools in teacher education: Tobin (1990) and Aubusson and Webb (1991) deliberately used metaphors to encourage science teachers to revise their teaching roles. In Tobin's research, initially most teachers provided metaphors that emphasized organisation and control but later changed to metaphors such as the teacher-as-musician. Developing metaphors of teaching and learning still is an essential feature of teacher development.

In closing this section of our own background regarding the role of metaphors (in the sense of conceptual metaphors) we would like to explain how our "classical" ideas were extended. In

2011, when Kai Niebert visited the Science and Mathematics Education Centre at Curtin as a postdoctoral scholar, he introduced Treagust to the term 'conceptual metaphor' and reintroduced the work of Lakoff and Johnson and the notion of embodiment in science through metaphors. Subsequent research at Curtin showed that good instructional metaphors and analogies need embodied sources (Niebert, Marsch, & Treagust, 2012).. According to philosophers,. Metaphors and analogies permeate all discourses, are fundamental to human thought and are not simply teaching tools. In other words, the students need to have previous experience with the metaphor or analogy – this goes beyond understanding the analog to further understand the target concept. "One of the most important revelations is that metaphor is not merely a linguistic phenomenon but also a fundamental principle of thought and action" (Niebert et al., 2012, p. 850).

COMMENTS ON THE THREE PAPERS

In our review, we start with the study that is nearest to "classical" conceptual change studies on students' conceptions research, the empirical investigation by Rachael Lancor on tertiary level students' conceptual metaphors of energy. We continue with the work by Kai Niebert and Harald Gropengießer who illustrate how the conceptual metaphor perspective may inform planning, carrying out and evaluating instructional sequences in science and even predicting students' difficulties of understanding certain science concepts. Finally, we discuss Hans Fuchs' development of a theoretical perspective of narrative framing on the grounds of conceptual metaphor perspectives.

Briefly summarised, our analyses draw on the key features in the referring literature:

(a) Conceptual metaphors are patterns of mappings between abstract concepts and bodily-based image schemas reflected in everyday language.

(b) Conceptual metaphors categorise the metaphors and analogies employed in understanding a certain topic at the level of the used source and target domain.

(c) For each of the studies presented, the underlying framework is that the image schemas (the gestalts) are structures of the embodied mind.

Paper 1: An Analysis of metaphors used by students to describe energy in an interdisciplinary General Science Course (Rachael Lancor)

In the abstract Rachael Lancor summarises the major features of her paper in that when students explain the role of energy "in five contexts that frequently appear in the media; radiation, transportation, generating electricity, earthquakes, and the big bang theory", …. they spontaneously use metaphorical language …. in multiple coherent ways"

Rachael Lancor (2012a, 2012b) has carried out a number of additional studies on understanding energy, drawing on the same theoretical framework (conceptual metaphor based) and the same qualitative research methods focussing on different groups of students. The findings of the present study fit well with the results of other studies in the field of teaching and learning energy (Chen et al., 2014). A particular strength is that the investigation of the use of energy in physics, chemistry and biology contexts identifies differences of students' views on energy within different disciplinary contexts. So far, most empirical research on teaching and learning energy has been carried out in the domain of physics (Duit, 2014).

Concerning the key method used to investigate understanding of energy, a conceptual metaphor perspective is explicitly adopted. However, it seems that a key feature of "conceptual metaphors" drawing on the conceptual metaphor school, namely that cognition is deeply embedded within bodily experiences is virtually absent (or implicit) throughout the paper. This seems to be the case for the other papers by Rachael Lancor as well. If we would replace the term "conceptual metaphor" when reading the papers by "students' conceptions" as used in the students' (alternative) conceptions field (Duit & Treagust, 2003) this would work well. In other words, it seems that key ideas of the conceptual metaphor field are not in the foreground. The added value of the conceptual metaphor perspective as compared to conceptual change ideas is not explicitly elaborated. As energy has proven to be a difficult concept to be learned (Duit, 2014), the role of conceptual metaphors to guide students towards understanding of key ideas of energy such as transfer, transformation, conservation and degradation is welcomed. In brief, this is an interesting study that reveals energy ideas of students who study a little science and may represent views of educated lay people.

Paper 2: Understanding starts at the mesocosm: Conceptual metaphor as a framework to develop external representations for science teaching (Kai Niebert and Harald Gropengießer)

This is a theoretically rich paper embedding key ideas of mainstream embodied cognition within theories on the role of multiple external representations in teaching and learning (e.g., Ainsworth, 2006; Treagust & Tsui, 2013) on the one hand and evolutionary epistemology (Vollmer, 1984) on the other hand. Consistent with research in the field, the multiple external representation perspective highlights that teaching and learning may become more effective if the same topic is modelled from various perspectives. The evolutionary epistemology provides a framework to better understand the particular role of embodied cognition issues. Vollmer (1984) distinguishes not only macroscopic and microscopic structures but also structures between the two which he refers to as mesocosmic. This is the domain of everyday life concerns and as argued by the authors is where understanding starts, being "that section of the real word we cope with perceiving and acting, sensually and motorically …." (Vollmer, 1984, p. 89). Niebert and Gropengießer argue that the framework of conceptual metaphors and Vollmer's epistemological distinctions of micro, meso and macrocosm can be used as diagnostic tools to predict student understanding.

Based on the outcomes from their studies, Niebert and Gropengießer put forth the argument that external representations, particularly those that involve action, visualisation, or reflection of past experiences, enable a deeper understanding of the concepts investigated. This is the notion of embodied cognition: Representations that involve action, visualisation or reflection of past experiences "shed light on the embodied conceptions that shape students' conceptual understanding" (p.34). Similarly, it is argued that "representations that visualise an image schema and its mapping on a scientific concept ….do not provide a new experience but induce an instance of *relived* experiences (p.34). As useful as this notion of lived experience may be, it is not necessarily the case that every individual is able to draw on past experiences when learning from external representations, like models, and this may be a limitation of learning by embodied cognition. The paper is rich concerning discussing instructional sequences based on the conceptual metaphor framework in significantly challenging difficult domains of science in school, namely, cell biology, neurobiology, the greenhouse effect and the carbon cycle particularly with the container schema and the balance schema. It should be noted in this paper (and also that of Fuchs) that concepts like a neuron are described metaphorically in terms of containers and having boundaries. A particularly interesting and significant facet is that according to evolutionary epistemology, the conceptual metaphors discussed developed during evolution of the human mind and hence they are particularly deeply rooted.

Paper 3: From Stories to Scientific Models and Back – Narrative Framing in Modern Macroscopic Physics (Hans Fuchs)

Narrative issues have played a significant role in science education research for a long time (e.g., Martin & Brower, 1991). The best known examples of such an orientation are "*story telling*" in science classes supporting students understanding science content and issues of the nature of science (e.g., Kubli, 2005) and "*science writing*" (Yore & Treagust, 2006) supporting understanding of these science issue by writing (brief) essays about science topics. Both issues are also mentioned in the present paper by Hans Fuchs. However, this article goes far beyond these latter ideas. Actually, a rich theoretical framework of what Fuchs calls "*narrative framing*" is developed on the grounds of conceptual metaphor ideas that enable both the framing of modern macroscopic physics as well as teaching and learning physics. The epistemological position Fuchs holds may be illustrated by the quote. "Physical science is figurative (it is a representation of our imagination, not the outside world)" (Fuchs, 2013).

It is interesting to learn that the narrative framing leads to particular insights into the roles of models in science and science teaching and learning. Fuchs argues, for instance, that narratives and simulations allow telling stories with models. However, storytelling does not *lead* to theory. Stories may suggest conceptions and models. Hence modelling may be seen in terms of storytelling. In other words, scientific structures have a narrative character, so learning about stories is good preparation for formal science, as is illustrated by Fuchs in the development and implementation of a primary school science curriculum in Italy. Briefly summarized, the perspective of narrative framing developed in the paper provides insights that may contribute to the further development of science education.

A minor remark concerns the use of the quantity of *Heat* by Fuchs in his paper. Fuchs views the everyday use of the term *Heat* as being associated with either the gestalt of the „Force of nature" as a whole or specifically the material-like fluid/caloric that is a component of it as is illustrated in the Winter Story. In this argument, Fuchs does not adopt the conventional conception of thermodynamics and so he does not mention that Heat in everyday discourse has various meanings, including the basic ideas of the physics concepts of heat, entropy and temperature (Kesidou, Duit, & Glynn, 1995).

In addition, we comment on an idea briefly discussed by Fuchs that presenting different domains of physics (such as heat and electricity) in "*analogous forms*" will ease understanding; the Karlsruhe Physics Course (Falk, Herrmann, & Schmid, 1983) is such an example. However, only a few studies on teaching and learning the various topics of this course are available (Starauschek, 2001; Kesidou & Duit, 1991). Support for this assumption is not convincing. Research on the role of analogies and metaphors in science teaching in general has shown that these teaching and learning aids are doubled edged swords (Glynn, 1991).

Finally, we comment on the complexity of the argumentation that Hans Fuchs presents in weaving together manifold theoretical perspectives. Clearly, this paper may provide a fresh view and hence understanding for thinking about science instruction as well as science education research. However, without reading more of his research work the complexity of all the major points presented is difficult to fully understand. Consequently, we believe that these rich and complex ideas need further simplification to inform science teachers how they might change their ways of thinking about science teaching and their teaching behaviours.

Concluding remarks

The three papers discussed above cover a wide range of studies in the spirit of conceptual metaphors – ranging from a study somewhat similar to “classical” conceptual change, to a teacher professional development approach informed by conceptual metaphor ideas, and finally to an elaborate theoretical perspective of “narrative framing”. In other words, there is much information on “conceptual metaphors in action” in science teaching and learning in these three papers and in the literature on conceptual metaphor in general. Each of the paper’s authors use the term conceptual metaphor in a different way and each way was supported by different theoretical perspectives; for Lancor, the framework of metaphor theory; for Fuchs, the theory of narrative framing; and for Niebert and Gropengießer, experientialism as the theory of embodied cognition with an emphasis on the mesocosm, the realm of lived experience.

We argue, based on our review of these three articles, that there is a need for more precise and operationally-defined use of the term conceptual metaphor or at least for the authors to identify which kind of conceptual metaphor is being used in their studies. Fuchs (2013) has clarified three different uses of the word metaphor ("at least in the metaphor theory of cognitive linguistics", p.5).

- Special linguistics metaphoric expressions - in narratives/stories
- Metaphors proper – that have a conceptual structure
- Metaphor as a process of metaphoric projection – from a source to a target domain

Consequently, we believe that in the field of research dealing with conceptual metaphors there needs to be a clear definition (or explication) what this term denotes. Surely cognition has to do with certain features of the human body that allow certain experiences, but which features are in the foreground? Which senses are involved? Psycho-motor actions of various kinds?

In addition, it seems to us that research on how the conceptual metaphor approach may become part of normal instructional practice is needed. In particular, it is necessary to theoretically elaborate the added value of the conceptual metaphor approach as compared to the so far dominating conceptual change view of teacher professional development approaches.

The papers argue that the connection between everyday thinking and scientific thinking is not superficial but is deeply embedded in action, visualisation, or reflection of past experiences or narratives. So, how can these ideas of metaphorical concepts be brought to the science classroom so that teachers can use the ideas effectively and efficiently? Lancor uses metaphors in teaching energy to students in university general science courses, Fuchs has designed and discusses the primary school curriculum and Niebert and Gropengießer illustrate many lessons so it is evident that practitioners can use conceptual metaphors in their teaching.

Finally, we would like to add a thought in which way the Model of Educational Reconstruction (Duit et al., 2012), which is theoretically based on classical conceptual change views, may be further developed. The process of educational reconstruction of science content for teaching and learning this content to certain groups of students may certainly gain significance if "metaphorical" issues as those provided by Fuchs (2013) are taken into account. Considering the basically metaphorical nature of science concepts and principles may lead to a "content structure for instruction" that more adequately addresses views of the nature of science as developed from the perspectives outlined in the present volume.

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