Embodied cognition as a framework for understanding science and sustainability

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Abstract: A review of the literature over the past decades shows how teachers and researchers have probed various external representations for teaching science and sustainability issues. These empirical findings give evidence for what every science teacher knows from his own practise: Some representations are more effective than others. We approach this issue based on the theoretical framework of embodied cognition that we utilize to analyse, explain and predict meaningful learning: Research has shown that metaphorical mappings between experience-based source domains and abstract target domains are omnipresent in everyday and scientific language. The theoretical framework of embodied cognition explains these findings based on the assumption that understanding is embodied. Embodied understanding arises from recurrent bodily and social experience with our environment. As our perception is adapted to a medium scale dimension, our embodied conceptions originate from this mesocosmic scale. With respect to this epistemological principle we distinguish between micro-, meso-and macrocosmic phenomena. We use these insights to analyse how external representations of phenomena in the micro-and macrocosm can foster learning when they a) address the students' learning demand by affording a mesocosmic experience or b) assist the reflection on embodied conceptions by representing their image-schematic structure. We base our considerations on empirical evidence from teaching experiments on phenomena from the microcosm (microbial growth, signal conduction in neurons) and the macrocosm (greenhouse effect, carbon cycle). We discuss how embodied cognition can inform the development of external representations

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Extended Summary

Conceptual metaphor as a theory within the framework of embodied cognition argues that understanding is ultimately grounded in embodied conceptions, either directly, or by imaginatively mapping its structure to the abstract concept to be understood. In contrast to embodied conceptions, that are understood directly, most science and sustainability concepts are based on models and generalisations derived from complex inquiry. Concepts derived from an often very intelligent but complex inquiry cannot be embodied in the same way as bodily experiences. Thus, they must be thought of in an imaginative way (Lakoff, 1990; Author, 2013).
Embodied cognition explains why we have problems in understanding science concepts like the theory of relativity, the theory of evolution, and the cell theory: They are of abstract nature and therefore imaginative thought is needed. The purpose of this study is to find out: *How can embodied conceptions inform the design of external representations of selected micro- and macrocosmic phenomena?*

Methods
Using the model of educational reconstruction (Duit, Gropengiesser, Kattmann, & Komorek, 2012; Author, 2013) as a research design we conducted teaching experiments (Steffe, Thompson, & Glasersfeld, 2000) with 118 students on concepts from microcosm (cell division, neurobiology) and macrocosm (greenhouse effect, carbon cycle). In these teaching experiments groups of 2-3 students probed learning activities that were developed based on students' conceptual and experiential needs. To this end we collected students' and scientists' conceptions on these topics, meant for the development of the learning activities, and analysed them based on embodied cognition to find out, what experiences guided their conceptions. Based on the differences and commonalities between scientists and students we defined the students' conceptual and experiential needs. To analyse the conceptions, all data were videotaped, transcribed and investigated using qualitative content analysis (Mayring, 2002) and metaphor analysis (Schmitt, 2005). The data are presented on the level of conceptual metaphors (Lakoff, 1990).

Results
In the interviews within our teaching experiments we found that the students' conceptions of cell division and neurobiology as well as of the greenhouse effect and the carbon cycle are far from the current scientific theory—but they still make sense to the students. A summary of the conceptual metaphors of scientists and students analysed in this paper is presented in Table 1.

Table 1: Conceptual Metaphors of Students and Scientists
Central conceptual metaphors of scientists and students discussed in this paper

Topic	Students' Conceptual Metaphors	Scientists' Conceptual Metaphors
Microbial growth	Organism Are Containing Cells	Organism Are Made of Cells
	Gene Is Containing Information DNA Is Containing Code, Code Is Sequence of Numbers	Gene Is Information DNA Is Code, Code Is Sequence of Bases

Topic	Students' Conceptual Metaphors	Scientists' Conceptual Metaphors
Signal conduction	Neuron Is Container	Neuron Is Container, Myelin Is Boundary of Container
Greenhouse effect	CO_2 Is Destroyer of Ozone Layer	CO_2 Is Capturing and Releasing Heat
	Greenhouse Effect Is More Input Greenhouse Effect Is Less Output	Greenhouse Effect Is Shifted Equilibrium
Carbon Cycle	CO_2 Is Man-Made, CO_2 Is Man-Made or Natural	Carbon Flow Is Manmade or Natural
	Constant CO_2-level By Constant Input Constant CO_2-level By Less Input than Output	Constant CO_2-level By Balanced Input and Output

An analysis of the conceptual metaphors students and scientists use to construe the selected phenomena reveals the mesocosmic experience they draw on. Contrasting students' and scientists' CMs is fruitful insofar as it provides a systematic perspective to categorise students' conceptions. Our analysis of the CMs revealed that only a limited number of image-schematic structures were employed in construing the four very different phenomena. Based on the conceptual metaphors presented in Table 1, we developed external representations to address students' alternative conceptions. To do so, we formulated the learning demand based on the gap between the CMs of students and those of scientists (Table 2).

Table 2: Addressing students' experiential demand via external representations

Topic	Learning demand	External representations
Microbial growth	Understand the ontology of cells	Microscopy of root-cells; reflection of part-whole-image-schema
	Understand the ontology of a gene. Reflect the conception codes.	Analyse original data sheets with DNA sequences
Saltatory signal conduction	Understand the isolating role of myelin.	Electromicroscopic photos of myelinated and demyelinated neurons.
Greenhouse effect	Experience the properties of CO_2 and reflect the container schema.	Experiment on the 'Greenhouse effect' to afford experience on the role of CO_2 in global warming, reflect on the absence of ozone.
	Understand the energy flows in global warming: Reflect on how balance schema is employed	Visualise balance schema to disclose and work with an implementation of the combined container- and balance schemata, reflect its mapping to the dynamic equilibrium in the greenhouse effect

Topic	Learning demand	External representations
Carbon cycle	Understand CO_2 as a natural element of the atmosphere.	Present original data of historical track record with CO_2 in the atmosphere.
	Understand that a constant CO_2-level means a balance in emission and removal: Reflect on how balance schema is employed	Visualise balance schema to disclose and work with an implementation of the combined container- and balance schemata, reflect its mapping to the dynamic equilibrium in the carbon cycle

The students' learning demand analysed in our study can be separated in two different types of requirements. First, some alternative conceptions occur as a result of students' repeated experiences with phenomena of their everyday world and an inadequate mapping of an image schematic structure. Second, other alternative conceptions can be traced back to missing experiences, which have to be made during science teaching. In the conceptual change framework these two approaches are discussed as 'misconceptions' and 'missing conceptions' (Aufschnaiter & Rogge, 2010). With these requirements in mind the external representations presented in our study can be separated into two categories:

- **External representations that address the experiential demand:** The students' CMs on the greenhouse effect showed that they lack an adequate idea of the role of CO_2 in global warming. In this case, no or inadequate conceptions can be traced back to a missing experience of the phenomenon; actually the learning demand reveals an experiential demand. To deal with this we provided an experience (simulate the greenhouse effect) to present the properties of CO_2.
  There are multiple representations that afford experiences of second-hand origin, such as photomicrographs, electromicrographs, chromatograms, recordings of action potentials, and a view of a DNA sequencing gel. These representations, whether of first- or second-hand origin, can prepare the ground for the development of conceptions. Representations that afford an experience of a phenomenon to be scientifically understood are of high importance for students. In our approach, the analysis of students' CMs was a prerequisite for the design of external representations that afford the essential experience.
- **External representations that disclose the image-schematic structure of concepts:** In the cases of understanding microbial growth, saltatory signal conduction, the atmospheric energy budget, and the CO_2-budget the students' CMs reveal that they refer to the same image schemata as scientists. Divergences in the conceptions are due to a difference in mapping this image schematic structure to the target domains. Tearing paper, working with and reflecting on toppling dominoes, and water flowing through a beaker are material representations of image schemata that students and scientists employ in understanding cell division, saltatory signal conduction, the carbon cycle, or the greenhouse effect. These material representations of cognitive schemata helped students to re-experience the inherent structure of the schema, identify its essential elements, and reflect on how they employ it in their effort to understand the phenomenon. This category of representation sheds light on the embodied conceptions that shape students' conceptual understanding. Models in classrooms often work in such a way that they provide new experiences students may use as a source for understanding.

Representations that visualise an image schema and its mapping on a scientific concept work differently. They do not provide *new* experience; they induce an instance of a *relived* embodied experience. By working with these external representations students have the chance to analyse the structure of this specific experience and reflect on their embodied cognition.

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