Embodied cognition as a framework to teach science

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Embodied cognition as a framework for designing and analysing external representations to teach science

Subject

A review of the extant literature over the past decades shows how science teachers and science education researchers have probed various external representations for teaching and learning. 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. In prior studies we analysed students' and scientists' conceptions on different phenomena based on this approach (Author et al. 2012, 2014). We were able to confirm Lakoff and Johnson's (2003) claim that understanding is grounded in bodily experience: Understanding science is not just a matter of using a multiplicity of imaginative thinking tools like metaphors, analogies, or models to bridge the gap between embodied thought and abstract science concepts. It is a matter of how these imaginative thinking tools assist students to construct scientific conceptions. As teachers use more external representations than metaphors and analogies to teach science, like different visualizations, models, task-based worksheets, interactive simulations, observations, photos, diagrams etc. we are widening our approach to the diverse range of external representations. In the paper we use embodied cognition as a lens to analyse: How can embodied cognition inform the analysis and design of external representations that foster an understanding of science concepts from micro- and macrocosm?

Theoretical and methodological framework

The theoretical 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 scientific concepts are based on models and generalisations derived from scientific 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. One line of reasoning points at the abstract nature of these theoretical notions and the necessity of imaginative thought. Closely related, but more basic is the argument for the lack of direct experience of these processes. Vollmer (1984) argues that our sensory system is not able to perceive or process phenomena like these. Our sensory and cognitive systems fit – at least partially – to the world we live in, because they have emerged in a process of adaptation to the world. Vollmer calls those parts of the real world to which man has been adapted with his perception, experience and actions the mesocosm. It is a world of middle dimensions: medium distances and times of low velocities and forces and low complexity.

While perception and experience in general are primarily influenced by the mesocosm, scientific evidence and theories often exceed the mesocosm: Macrocosmic structures like the biosphere, the solar system, or the mass of the moon or are not part of the mesocosm. The same holds for microcosmic entities such as cells or structures like molecules. Our embodied concepts and schemata are of mesocosmic origin. We are confined to comprehend microcosmic as well as macrocosmic

phenomena in terms of these mesocosmic concepts and schemata. Scientific understanding depends to a large degree on technologically extended perception and imagination. This insight bears important consequences for instructional interventions.
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 52 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).

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. The metaphor analysis shows that the students employ specific experiences conceptualized in schemata to understand these topics from the micro- and macrocosms:

- To understand the process of cell division students employ a division schema that is shaped by everyday-experiences of division (*dividing is becoming smaller or becoming more*) and not by a scientific understanding (*cell division is dividing and growing*).
- To understand the signal transduction in neurons students and scientists imagine the neuron as being a *container* where signals *travel* from one *side* to *another*. From a scientific view the time of travel depends on the diameter of the neuron and its isolation by myelin, which makes the signal *jump* from one node to another. Students have serious problems understanding how isolating a neuron can affect the signal transduction.
- To understand the carbon cycle students and scientists employ a container-flow schema: While scientists explain climate change by a *man-made emission* of CO_2 from the container *fossil carbon* into the container *atmosphere*, students explain climate change based on a emission of *man-made* CO_2 that has devastating properties.
- In understanding the greenhouse effect students and scientists refer to the experience-based balance-schema: While students either imagine the cause of climate change as more energy *coming in* (due to an ozone hole) or less energy *going out* (due to a thicker greenhouse gas layer) scientists imagine global warming as caused by a *shift* in the atmospheric *energy budget*.

The analysis of students and scientists conceptions in the four cases show that according to embodied cognition students and scientists refer to embodied experiences of containers, balances, flows, division etc. to imagine scientific conceptions of phenomena from micro and macrocosm. To engender students understanding of these phenomena we provided representations that not just denoted a scientific conceptions but afforded experience and helped them to reflect their embodied conceptions:

Representations to teach and learn in micro- and macrocosm

type of external representation	denote conception	afford experience	reflect embodied conception
effect of external representation	reconstruction of scientific conceptions	first or second hand scientific experience of a phenomenon	reflect the mapping of an embodied conception used as source for understanding
Instance of cell division	text about mitosis	microscopic image of mitosis in root cells	breaking a bar of chocolate, reflecting division schema
Instance of neurobiology	text on saltatory conduction	photos, story of patient with multiple sclerosis	role play, reflecting analogical experiment
Instance of the carbon cycle	diagram from IPCC	provide carbon containing materials	work with and reflect on container-flow-model
Instance of the greenhouse effect	conceptions on the greenhouse effect	providing experiments on the properties of CO_2	reflection of dynamic equilibrium

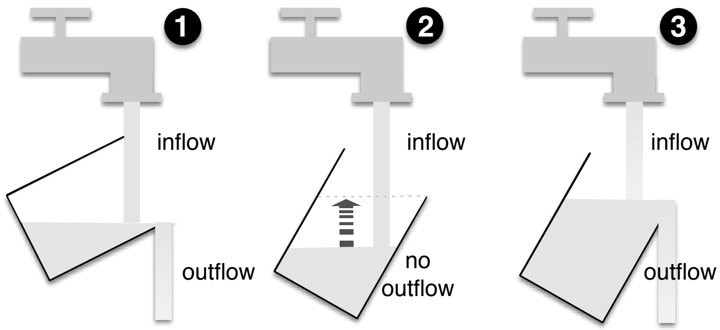
To make the effect of the representations more explicit we exemplarily present the results from teaching the greenhouse effect with the representations presented above:

A review of literature shows that there is a widespread confusion of the greenhouse effect and ozone depletion as causes of climate change (Ekborg & Areskoug, 2006; Koulaidis & Christidou, 1999). In an analysis of the metaphors students' and scientists' use to understand climate change we have shown that both are thinking of the atmosphere in terms of a container in using terms like *into*, *out*, *leaving*, *incoming*, *outgoing* or *contain* Author, 2012). Using these findings we developed an experiment that materialised the container schema as a glass box. In contrast to common versions of this experiment, we did not use closed bags or boxes but rather open-top boxes. This addresses the students' idea that CO_2 attacks the boundary of the container: We planned to lead students into a cognitive conflict by experiencing a warming of the open box with CO_2. When there is no upper boundary, nothing can be attacked; so the warming has to be due to other mechanism.

Fred was one of 18 students who worked in this learning activity. The following excerpt reveals his conceptual development: "*I thought that the ozone hole causes global warming. However, it is the CO_2 and not the ozone. You can see that the temperature in the box with CO_2 rises higher. [...] The CO_2 stores the heat in the box. Perhaps the heat gets into the CO_2 molecules.*"

Initially, Fred believed that climate change is the result of a hole in the ozone layer. While conducting the experiment, he explains the warming by conceptualising CO_2 as an aggregate of small containers (into the molecules, molecules store heat). The idea of storing heat in molecules may not be adequate from a thermodynamic perspective that conceptualises temperature as the vibration and thermal motion of molecules. However, from a phenomenological perspective, Fred's conception is comprehensible and sufficient to explain the causes of global warming. This particular example shows that the learning activity helps to narrow down on CO_2 as the cause of global

warming. In describing the experimental set-up, every student recognised that there is no ozone involved in this experiment and, consequently, in the warming (Author, 2014).
After working with this experiment we provided an experiment to understand the nature of dynamic equilibrium (see Figure). From the perspective of embodied cognition this experiment focused on helping students to reflect their mapping of the balance schema in global warming.



Modelling dynamic equilibrium. A beaker is fixed on a stand under a water tap and tilted. Students are asked to analogise the amount of water in the beaker with the amount of heat in the atmosphere.

After conducting the experiment the students were asked to reflect conceptions on the greenhouse effect. For this purpose we prepared cards with different conceptions on global warming just without tagging the conceptions as everyday or scientific conception. The conceptions as sketched and written on the cards explicitly use the container schema. The following conversation upon students was typical when arguing about the different conceptions:
Max: *"The idea »warming by more input« was what we initially thought. But it cannot be that way, because this would mean the ozone hole is involved – and it isn't. It's the CO_2 that stores the heat in the box. So it must be »warming by less output«."*
Luke: *"Yes. [5 sec. pause] But if it is less output, more and more heat is captured in the atmosphere. The temperature would rise to infinity. […] I think it must be this »new equilibrium«. Like in this experiment with the equilibrium."*
Max: *"Yes, CO_2 stores heat and gives it away again. But the more CO_2 is in the atmosphere the more heat is stored. […] It is like my pocket money: Until my birthday I got 10 € a week – and spent everything. Now I get 15 € every week and there is noting left at the end of the week, too. But now I can afford to go to the cinema in every week."*
In their argumentation the students Max and Luke connected the experience they made during the experiments to the schemata they use to understand global warming: At first they rejected the idea »warming by more input« and switched to the idea of the greenhouse effect. This mechanism of capturing heat rays is a conception as it is presented in some textbooks, too. It is an oversimplified idea of the energy budget which is not appropriate to achieve an adequate understanding (Author, 2014). The experience of a dynamic equilibrium obviously helped the students to construct the scientific idea of global warming. In our teaching experiments 8 of 12 students successfully constructed the scientific conception of a shifted equilibrium within earth's energy budget. At the end of the teaching experiment Max reflects the scientific conception and the schemata he uses to everyday experience of getting and spending pocket money. Obviously the experience and reflection of the container and the balance schemata not only enabled him to discuss the scientific conception but his everyday experiences, too. We think this works for him because time is often perceived as a container (Lakoff & Johnson, 2003) and the incoming and outgoing money per

week are interpreted as an equilibrium, too. Therefore the students can use the same resources for understanding the energy budget of the atmosphere as their own "fiscal budget". Reflecting these resources of understanding brings some evidence for Max's metaconceptual awareness in mapping his conceptions of processes in macrocosm and mesocosm to his experiences.

Conclusion

For many decades a tradition of research emerged that collected students' conceptions as to *describe* how students understand certain science concepts. In the last years several researchers in science education adapted the theoretical framework of embodied cognition to science education. Thereby embodied cognition was used fruitfully to *explain* why students think the way they think, i.e. understand students' understanding.

We adapted Vollmer's distinction of meso- mirco- and macrocosm to science education as a diagnostic tool that serves to prognose degrees of students' difficulties in understanding. As understanding is firmly grounded in experience and thus in mesocosm, understanding outside this dimension needs to be rooted in this dimension. We took this central claim of embodied cognition to elaborate the prescriptive value of this theoretical framework: We found some evidence that a combination of external representations that afford experience, denote conceptions or help students to reflect on embodied conceptions they use to understand science concepts can engender their conceptual understanding.

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