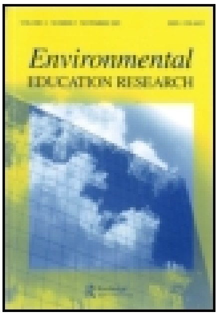

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Understanding and communicating climate change in metaphors

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Understanding and communicating climate change in metaphors

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An analysis of students' conceptions on climate change shows a great confusion on key aspects of global warming. Even after instruction students often hold conceptions that differ from scientists' conceptions. Student's conceptions on global warming were collected in a reanalysis of 24 studies on everyday concepts of global warming as well as in an own interview study with 35 18-year-old students from German grammar schools. Climate-scientists conceptions were analysed from textbooks and research reports in a literature study. All data were analysed by systematic metaphor analysis and qualitative content analysis. Experientialism as a theory of metaphor provided insight in the process of understanding. The analysis of conceptions by experientialism shows that students and scientists have different metaphorical conceptions of global warming – but both refer to the same schemata. These schemata in mind we categorised the conceptions of global warming. Hereby we identified different thinking patterns in students' and scientists' conceptions. Following the model of educational reconstruction we took the metaphorical conceptions as a starting point for the development of learning environments. By uncovering the – mostly unconsciously – employed schemata, we gave students access to their metaphorical conceptions and let them reflect on their mental models.

Keywords: analogy; climate change; conceptions; educational reconstruction; experientialism; metaphor

1. Introduction

In the last two decades, climate change made its way from being a sophisticated topic in science journals to being broadly discussed in the media, politics and schools. In parallel an increasing number of papers emerged that documented everyday conceptions on global warming, which are often very different from the scientific perspective. In the study on hand, we want to offer a new perspective on these findings by analysing the experience-based source of conceptions on climate change. Based on this analysis and own teaching experiments, we want to suggest learning environments that address the students' conceptions by referring to their experiential sources. In our study, we interviewed 35 18-year-old students in German schools regarding their beliefs about the causes and processes of climate change. A typical answer was given by the student Emily:

> CO_2 is a man-made gas that bites a hole in the ozone layer. Through this hole, more sun rays enter the atmosphere and it warms up. (Emily 18 yrs.)

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Emily believes that climate change is caused by CO_2, which she imagines to be a man-made gas that causes holes in the atmosphere. These holes allow increased radiation from the sun's rays. Scientists relate global warming to an increased greenhouse effect caused by greenhouse gases like CO_2 that absorb infrared radiation. The majority of these greenhouse gases are from natural and not from man-made sources, causing a natural greenhouse effect. This effect is increased by man-made emissions of additional greenhouse gases. Emily and the scientist are in partial accordance as pertains CO_2 as a cause and the effect of warming but in sharp contrast as to explain the causal connexion. Emily is not alone in her scientifically incorrect way of explanation. We analysed 24 studies published in refereed journals dealing with conceptions of climate change (Niebert 2010). These studies collected data from primary-school, high-school and university students, educated laypeople and adults with and without science degrees. The data were collected in different parts of the world, including Europe, the USA, Canada, Asia and Australia. Nevertheless, the results were similar everywhere. Most students and educated laypeople

- Confuse different environmental problems related to the atmosphere, such as the greenhouse effect, the ozone hole and air pollution. The most prominent explanation for global warming is that the ozone hole causes climate change (Bostrom et al. 1994; Boyes and Stanisstreet 1997; Read et al. 1994).
- Mix up the causes for the emissions of greenhouse gases and their effects on the atmosphere. Often, they describe the burning of fossil fuel as the only source of greenhouse gases (Koulaidis and Christidou 1999; Sterman and Booth-Sweeney 2007).
- Often relate scientifically inadequate conceptions – even after instruction (Ekborg and Areskoug 2006; Pruneau et al. 2001).

Our study is an evidence-based and theory-guided development of learning environments on the key issues of global warming: CO_2 emissions and the greenhouse effect. Unlike other studies, we adopted Lakoff and Johnson's theory of metaphor (Johnson 1987; Lakoff 1987; Lakoff and Johnson 1980) and analysed the experiential sources of students' and scientists' conceptions. Viewing Emily's conceptions through the lens of experientialism, she uses metaphorical terms, such as 'CO_2 bites a hole', 'a man-made gas' and 'enter the atmosphere'.

2. Interpreting the experience based frame of conceptions

To analyse the source of students' and scientists' conceptions, we refer to theoretical considerations and empirical findings emerging from the fields of linguistics (Lakoff 1987; Lakoff and Johnson 1980), philosophy (Johnson 1987), science education (Gropengießer 2007) and neurobiology (Gallese and Lakoff 2005; Rohrer 2001, 2005).

These findings, summarised as the theory of experientialism, hold that abstract concepts – this refers to most concepts in science – are understood imaginatively, thereby drawing on directly meaningful concepts and schemata. These basic conceptions are embodied, that is, they are grounded in bodily experience with our physical and social environment, i.e. perception, body movement (Lakoff 1987). Experiences such as up and down, centre and periphery, front and back and inside and outside are conceptualised through schemata, which are conceptualisations of recurring, dynamic patterns of our perceptual interactions and motor programmes. Schemata give coherence and structure to our experiences. The verticality schema, for instance, emerges from our tendency to employ an up-down orientation in picking out meaningful structures of our experience. We grasp this structure of verticality repeatedly in thousands of perceptions and activities every day, such as standing upright, climbing stairs or experiencing the rising of the water level in the bathtub. The verticality schema is the abstract structure of these up-down experiences, images and perceptions (Johnson 1987). Several other schemata, such as the container schema or the balance schema, are conceptual structures grounded in bodily experience and can be understood directly. These schemata shape our conceptual understanding not only in everyday life but also in science. The well-understood structures of the schemata as a source domain are projected onto the abstract scientific target domains. Thus, scientific understanding, as abstract it may be, is ultimately grounded in embodied conceptions.

Obviously, conceptions of climate change cannot be embodied in the same way as the above-mentioned schemata: While the daily weather with its continuous change in temperature, clouds, sun and rain is open for direct experience, climate is not. Climate is defined as the average weather pattern in a region over 30 years (Houghton 2002). The changes in climate do not occur on a time scale that is immediately obvious to us. We can observe daily weather changes but subtle climate changes are not as readily open for experience. Thus, climate change must be thought of in an imaginative way. Imaginative thinking is accomplished mainly by metaphors. Thus, guided by experientialism, we distinguish between embodied conceptions and imaginative conceptions. The latter are not directly grounded in experience but draw on the structure of our experience; we use our embodied schemata to explain abstract phenomena. Thus, imagination can be seen as bridging the gap between experience and abstract phenomena. We employ conceptions from a source domain (i.e. the container schema) and map them onto an abstract target domain (i.e. atmosphere) to understand abstract phenomena. Thus, the use of imagination requires source-target mapping. The structure of a source domain is projected onto a target domain. On the basis of this framework, we analysed not only the conceptions of students but also the conceptions of scientists.

The concept of developing fruitful learning environments not only based on the scientific perspective as stated in textbooks or research reports but as well on students' conceptions and thus their learning demand is based on the model of educational reconstruction (Duit, Gropengießer, and Kattmann 2005). In this model, students' and scientists' conceptions are compared to develop effective teaching and learning activities. We extracted scientists' conceptions from various scientific textbooks and the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007). Students' conceptions of global warming were sampled in a reanalysis of 24 empirical studies on everyday concepts of global warming (for the complete list see Niebert 2010), our own interview study ($n = 11$, 18 years, five female, six male) and during our teaching experiments ($n = 24$, 18 years, 11 female, 13 male). All students attended secondary schools in northern Germany and had no prior instruction in climate change. On the basis of the educational reconstruction of global warming, we set up and evaluated learning environments in 10 teaching experiments. In our teaching experiments, which lasted approximately 65–90 min, we examined learning processes in small groups of two or three students (Figure 1).

Following experientialism, we hold to the view that language and thought are based on the same conceptual structures. Language is therefore a window into students' conceptions. We distinguish between three domains: cognition, language and reality in a broad sense (Gropengießer 2003; Richards and Ogden 1923). Conceptions belong to the cognitive domain; they are expressed on the linguistic level through various symbols of speech or drawing. Therefore, students' statements are regarded as representations of their conceptions. A conception refers to a specific referent: an object, phenomenon or occurrence. Thus, to analyse the conceptions, all data were audio-taped (interview study) or videotaped (teaching experiments), transcribed and investigated using qualitative content analysis (Mayring 2002) and metaphor analysis (Schmitt 2005).

In the course of qualitative content analysis, we developed categories in the following steps: (1) transcription of the interviews and editing the texts to improve readability, (2) rearrangement of statements by content, (3) interpretation of the statements aiming at the underlying conceptions and (4) revision and final formulation of the categories. The metaphor analysis provides the basis for our interpretation of the conceptions from the perspective of experientialism. In our study, we identified a metaphor by a term or sequence that has or may have more than one meaning. In the first step, (1) we identified all metaphors in the material and (2) chose the metaphors that were crucial for the understanding of climate change. Subsequently, we arranged all metaphors with the same target and source domains and (3) described the metaphorical patterns used by the students and scientists. The results of the metaphor analysis were integrated into the interpretation of the conceptions during qualitative content analysis.

To assure the quality of the data analysis, all data were externally and consensually validated (Steinke 2004) by discussion in our working group and cross-checked with other studies in the field. The teaching experiments and the interviews were conducted by the article's first author. Wilbers and Duit (2001) describe the simultaneous role of the researcher as interviewer and teacher as beneficial for studies in science education because the research situation resembles an authentic classroom.

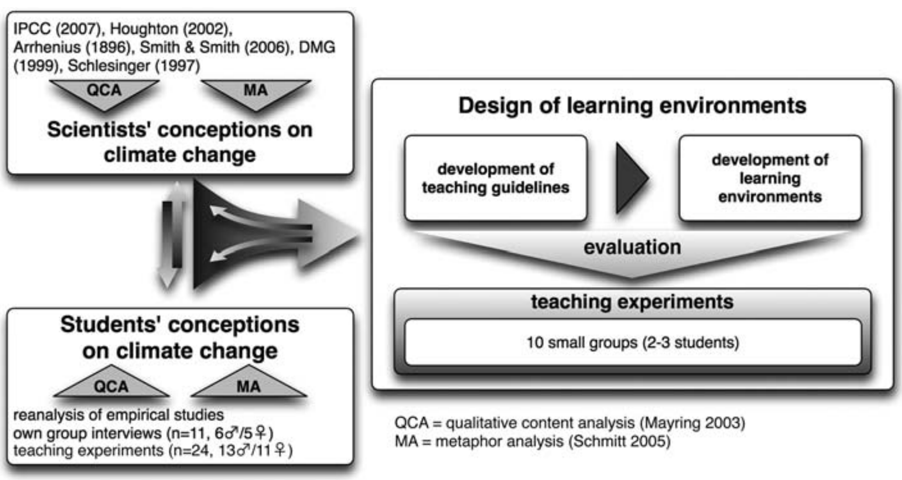


Figure 1. Research design – the model of educational reconstruction.

3. Conceptions and metaphors of climate change

The aim of this study is a theory-guided development and evaluation of learning environments on climate change. To realise this aim, we analysed students' and scientists' conceptions regarding their experiential basis. On the basis of these findings we developed learning environments such as experiments, narratives and models and evaluated them. In the following section, students' and scientists' conceptions of (1) the emission of CO_2 and (2) the effects of CO_2 in the atmosphere are analysed, and the relevant learning environments are described and evaluated.

3.1. Conceptions of the greenhouse effect

Different conceptions of global warming were identified in our study. In the light of experientialism, students and scientists explain the mechanisms of global warming using a container-flow schema.

3.1.1. Scientists' conception: warming by a greenhouse atmosphere

In 1896, Svante Arrhenius was the first to describe the effects of rising CO_2 concentrations on the climate. Since the United Nation's Intergovernmental Panel on Climate Change began publishing its assessment reports, research on climate change has become a major field in climate research. Scientists relate global warming to a change in the earth's radiation budget due to an intensified greenhouse effect. To explain the greenhouse effect, scientists refer to the container schema (cf. Figure 2):

> The solar radiation coming in is balanced by thermal radiation leaving the top of the atmosphere. (Houghton 2002, 257)

> […] incoming solar radiation and outgoing infrared (thermal) radiation […]. (IPCC 2007, 136)

To interpret these conceptions, which are grounded in the experience-based container schema, we analysed the structure of this schema to get a deeper understanding of the scientists' understanding of the greenhouse effect.

Using the container schema, the atmosphere is conceptualised as a container to describe the flows of radiation between the inside and the outside. Additionally, a balance schema is used to describe equilibrium between the in- and outflows. With the conception of atmosphere is a container, the surface of the earth is used as lower boundary and an outward boundary is conceived at convenient heights where changes take place, e.g. the tropopause. The interior of the container consists of

The container schema is based on the experience that our body is a container with a sharp border between inside and outside crossed by inputs and outputs (Johnson 1987). The schema is structured by the elements "inside", "boundary", "outside" and "content".

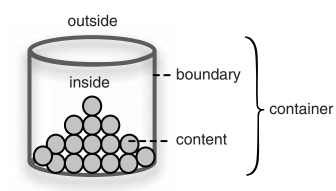


Figure 2. The container schema.

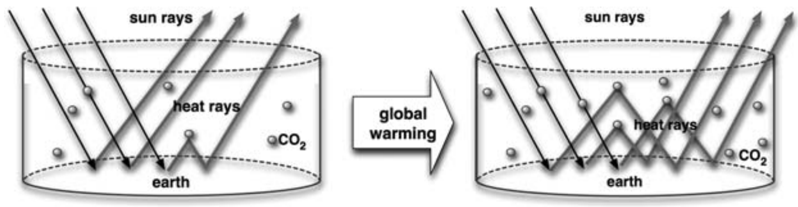


Figure 3. Warming by greenhouse atmosphere.

gases. The outward boundary is drawn to describe and quantify the energy flows between the atmosphere and space. The surface of the earth is conceptualised as the lower boundary of the container, which is crossed by energy and gases:

> The atmosphere of a planet is a gaseous envelope […]. (Houghton 2002, 1)

> […] movements of […] carbon dioxide into and out of the atmosphere […]. (Houghton 2002, 252)

The greenhouse gases, such as CO_2, are responsible for the warming of the atmosphere:

> The greenhouse effect [occurs in an] atmosphere that is more transparent to solar radiation than to infrared radiation. [IR-radiation] emitted by the planetary surface is absorbed by greenhouse gases. […] greenhouse gases are increasing, thus leading to an enhanced greenhouse effect. (Houghton 2002, 3, 255)

The conceptions of the greenhouse effect are based on two different elements enacting with the 'container atmosphere': radiation and CO_2. Scientists regard radiation as electromagnetic energy, which has various wavelengths and related frequencies in a continuous spectrum. A relevant distinction in solar radiation is drawn between visible light (the short-wave section of the spectrum) and heat (infrared radiation). The visible light is absorbed by the earth's surface and reemitted as infrared radiation. Visible light passes CO_2 unaffected, but infrared radiation interacts with CO_2, raising its temperature. Rising CO_2 levels in the atmosphere absorb more infrared radiation in the atmosphere. The more CO_2 is in the atmosphere, the more radiation is absorbed. We call this conception as warming by greenhouse atmosphere (see Figure 3).

3.1.2. Students' conception: warming by holes in the ozone layer

In the Introduction, we presented Emily's conception of a warming earth by a hole in the ozone layer. For a broader understanding of this conception, we give two more examples of students holding this conception:

> CO_2 destroys the ozone layer. Radiation coming from the sun passes into the atmosphere through the layer and heats up the earth. (Detlef, 18 yrs.)

> The ozone hole is getting bigger, because of more industrial emissions of CO_2. CO_2 attacks the ozone layer and thus more sunrays enter the atmosphere and warm the earth. (Nanni, 18 yrs.)

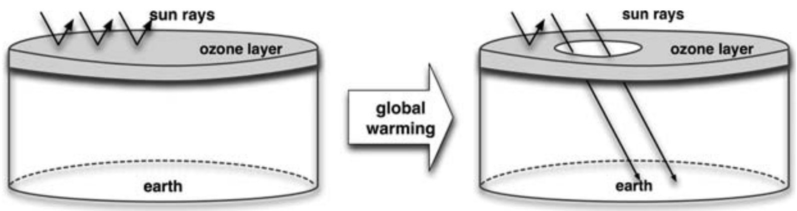


Figure 4. Warming ozone hole.

With this conception, students imagine the mechanisms causing global warming as follows. Normally, the ozone layer reflects some sunrays back into space. CO_2 causes a hole in the ozone layer, sunrays penetrate the layer through the hole and warm the earth.

In our study, 15 of 22 students expressed the conception that more sunrays pass through a hole in the atmospheric protection shield of the 'ozone layer'. Metaphor analysis indicates students' use of the container schema to describe the mechanisms of global warming. Terms such as 'passes into the atmosphere', 'through the layer' or 'sunrays enter the atmosphere' indicate that the atmosphere is imagined as a container with the ozone layer as a shielding boundary. In the students' conceptions, devastating qualities are attributed to CO_2: it 'attacks', 'destroys' or 'bites'. With anthropomorphisms like these, students strive to grasp the idea of how a hole can get into the 'ozone layer' atmospheric protection shield.

Students using this conception do not distinguish between visible light (short-wave radiation) and heat (long-wave radiation). From an experientialist point of view, this phenomenon is not surprising because we experience the sunrays as both bright and warming. In our everyday life, we are not aware of the absorption of visible light by our skin, the resulting increased movement of molecules in our body that leads to warming and the emission of heat over the body's surface. What we recognise is just: we feel warm if the sun shines down on us. Thus, it is not surprising that the students hold the conception that the more sunrays there are, the warmer it is (see Figure 4).

The hybridisation of the ozone problem with the greenhouse effect is a well-established finding in science education research (e.g. Ekborg and Areskoug 2006; Koulaidis and Christidou 1999). The concept of a perforated atmospheric protection shield leads to a simple idea: the atmosphere warms up because more heat gets in.

3.1.3. Students' conception: warming by greenhouse effect

In our interviews with students about global warming, we identified another conception that seems quite similar to the concepts expressed by the scientists: warming by greenhouse effect.

> The sunrays are absorbed by the earth's surface. […] The heat is released again, but a layer of greenhouse gases hinders the heat going back into space. So the heat stays in the atmosphere. (Claudia, 18 yrs.)

> A layer of CO_2 hinders the visible light coming to earth from going back into space again and reflects the light back to earth. So it gets warmer in the atmosphere. (Jürgen, 18 yrs.)

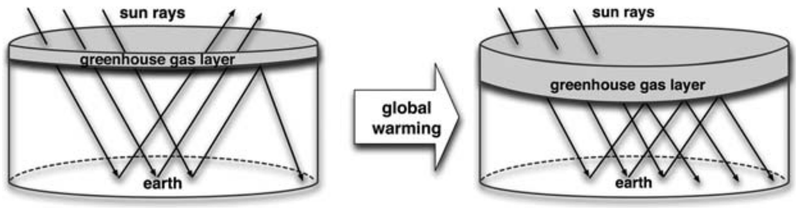


Figure 5. Warming by greenhouse effect.

In this conception, the greenhouse gases (mainly CO_2) form a special layer in the atmosphere, which is permeable for sunrays but nearly impermeable for the radiation coming from the earth. This conception is also based on the container schema ('into space' and 'in the atmosphere'). The conception is similar to the greenhouse effect communicated in the media or in schoolbooks. The central element of this conception is a layer of greenhouse gases that acts as a barrier that becomes thicker and thus less permeable. Therefore, the heat radiation is captured under the greenhouse gas layer in the atmosphere. The basic idea is that the earth warms up because less heat gets out or, even more simply, warming by less output. In contrast to the scientists who claim that evenly distributed CO_2 captures the heat in the atmosphere, in students' conception, the CO_2 is not evenly distributed in the atmosphere but forms the upper layer of the atmosphere (see Figure 5).

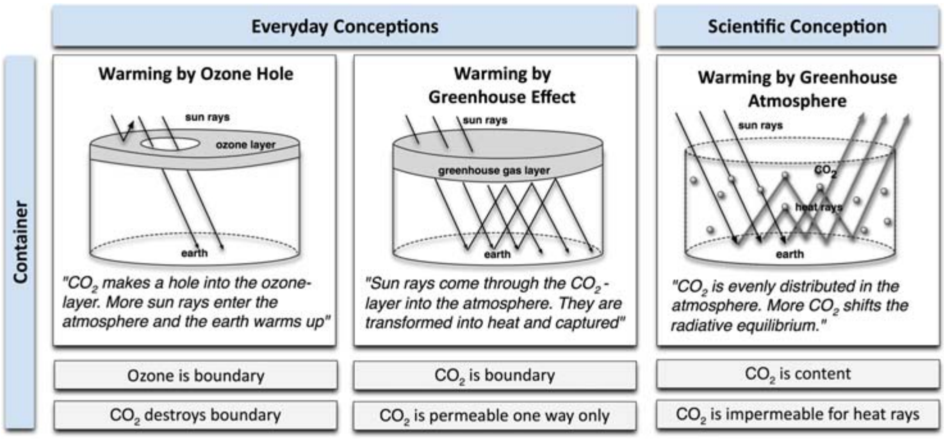
3.1.4. Comparison of conceptions of the mechanisms of global warming

The commonalities and differences between the conceptions are compared in Table 1.

The comparison shows different mappings of the container schema to the target domain of climate change. In all conceptions, the atmosphere is understood as a container. However, students and scientists map the container schema differently on the atmosphere, depending whether the container's boundary is thought to be made of a CO_2 layer (greenhouse effect), an ozone layer (ozone hole) or just assumed (scientists). CO_2 is conceptualised in different roles in relation to the container: whether it destroys the container's border (ozone hole), is permeable one way (greenhouse effect) or is permeable for sunrays but impermeable for infrared rays (scientists).

From a science educators point of view, the metaphor of the greenhouse effect that analogises the events in the atmosphere with those in a glasshouse is problematic. The atmosphere is warming because of a selective absorption of heat by climate-active gases. The glasshouse instead is first and foremost warming because glass windows suppress the circulation of air and thus the convection of heat. This scientifically not adequate mapping of the source (greenhouse) to the target (atmosphere) is not recognised by the students. The greenhouse effect is understood in terms of its impacts and not by its underlying mechanisms. The metaphor works because the warmer inside of a glasshouse is open for direct experience. And this experience is mapped to the atmosphere. But why it is warming in the glasshouse is not open for everyday experience and not understood by the students. Or in other words: the greenhouse metaphor works because no student understands the mecha-

Table 1. Conceptions of the processes of global warming.



nisms in a greenhouse. Strictly speaking, the greenhouse metaphor might be adequate to describe that it is warming in the atmosphere but not why it is warming.

From an experientialist's perspective, we base learning about climate change on the principle of 'reconstructing the container'. Students should

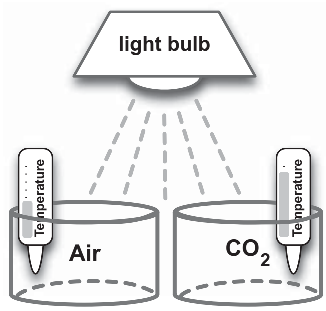
- Reflect on the border of the containers: is it an ozone layer, a CO_2 layer or just assumed?
- Reflect on the role of the CO_2: does it form the border of the container or is it the content? Does it destroy the border or trap heat?

The next section shows how learning environments can facilitate this reflection.

3.2. Understanding the greenhouse effect: reconstructing the container

To analyse whether and how learning environments influence students' conceptions, we evaluated the learning environments in teaching experiments. Teaching experiments (Riemeier and Gropengießer 2008; Steffe and D'Ambrosio 1996) provide empirical opportunities to combine interview situations (investigational aspect) with teaching (interventional aspect). The analysis of our teaching experiments provided information about the students' pre-instructional conceptions and their development in the course of the teaching process. The role of the researcher is twofold: to identify students' conceptions as an interviewer and to organise learning activities as a teacher depending on students' conceptions. In the teaching experiments, students were offered learning environments matching their conceptions. Each teaching experiment was carried out by the first author in small groups of two or three students on the premises of the Leibniz Universität Hannover. The teaching experiments were videotaped for a process-based analysis of students' conceptual development.

As we have shown above, the understanding of the greenhouse effect is based on the container schema. Differences between a scientific understanding and everyday conceptions originate from different ways of mapping the structures of the container to the structures of the atmosphere. Thus, we developed learning



Two glass boxes were filled with CO_2 (right box) and air (left box). Both boxes had an open top, black bottoms and were irradiated with a strong light bulb (200 W). The temperature was measured. It rose in the box filled with CO_2 about 2 degrees centigrade higher than in the box filled with air. Students were asked to interpret the phenomenon.

Figure 6. Reconstructing the container.

environments that helped students to reflect on the mapping of the container schema for climate change. The students carried out an experiment in that the container schema was materialised as a glass box and asked students to analogise the box and the atmosphere (Figure 6).

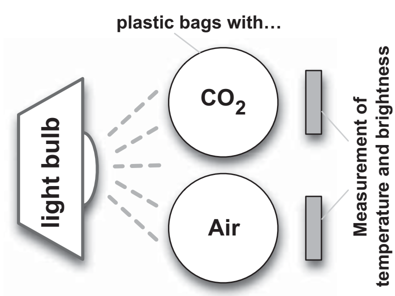
In one of our teaching experiments, the student Max shows his conception based on working on the learning environment:

> Initially, we said that it gets warmer because CO_2 destroys the ozone layer. But here we have no ozone layer and no ozone hole. But the container with the CO_2 heats up for two degrees anyway. How is the CO_2 doing this? I don't know. (Max)

Initially, Max holds the conception that climate change is due to an ozone hole caused by CO_2. During the experiment, he recognises a heating of the container with the CO_2 and notes that there is no ozone layer that caps the container. Thus, his observations lead him into a cognitive conflict with his initial conception. He still blames CO_2 for the heating, but he has no idea of the mechanism. Thus, he carried out another experiment that focused on the role of CO_2 in global warming (Figure 7).

This experiment helps Max to recognise the relevant properties of CO_2 and thus the content of the container.

> Despite the content, both bags are treated equal. The visible light goes through the bags. Behind the bag with the air, it is warmer than behind the bag with CO_2. Thus, CO_2 will absorb the heat. The heat stays in the bag. […] So my theory is: the CO_2 in the atmosphere captures the heat and thus it gets warmer. (Max)



Two plastic bags, one filled with air and the other filled with CO_2, were illuminated with a light bulb on one side. On the opposite side of the bags, the brightness and temperature were measured. While the brightness was the same behind both bags, the temperature behind the bag filled with CO_2 was 1.5 °C lower than behind the plastic bag because CO_2 absorbs the heat.

Figure 7. (Im)permeable CO_2.

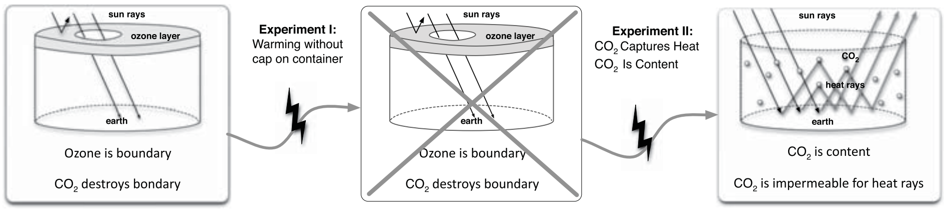


Figure 8. Max's thinking pathway: reconstructing the container.

Max describes both bags as transparent for visible light. He also recognises that it is warmer behind the bag filled with air than behind the bag filled with CO_2. He interprets his observations in the intended way: CO_2 is transparent for light and not transparent for heat, while air is transparent for both. After interpreting the experiment, he relates his hypotheses to the atmosphere and relates global warming to the capturing of heat due to CO_2 (see Figure 8).

Inspired by both experiments, Max reconstructs his mapping of the container schema to the atmosphere. While a hole in the container's boundary is initially blamed for letting the heat into the container, the first experiment leads to a cognitive conflict, and Max subsequently rejects this conception. The second experiment allows Max to experience the effect of CO_2 in global warming on a small scale. Animated by this experiment, he develops the idea that CO_2 as the container's content (the CO_2 in the atmosphere) is causing global warming by trapping the heat. Thus, he reconstructs not only the role of the container's boundary but also the role of the content, from disrupting (causing the hole) to capturing (trapping the heat).

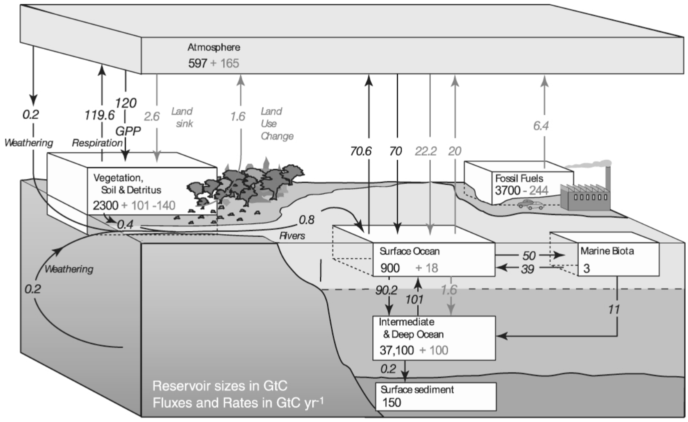
In analysing our data, we wondered whether reflection on materialised representations of embodied schemata could foster students' learning in general. Thus, we analysed conceptions and learning environments on another scientific topic related to climate change: the global carbon cycle.

3.3. Conceptions of the global carbon cycle

In our interview study, CO_2 was cited as the most important cause of global warming by both scientists and students. However, our results also underline the findings of Hildebrandt (2006), who has shown that students' conceptions of the biogeochemical processes of the global carbon cycle differ from scientists' conceptions. In the following section, conceptions of the emission of CO_2 and the carbon cycle are presented, starting with the scientific perspective.

The IPCC report describes global carbon flows between different carbon pools. In the diagram (cf. Table 2), the pools are indicated as boxes and the flows as arrows; the flow rates and pool sizes are indicated by figures. Carbon seesaws between the boxes and cannot be lost. Carbon may return on its path to one of the boxes from which it came; this phenomenon is understood as the cycling of carbon. The figure illustrates this conception. From an outside perspective the carbon cycle as a closed system is always in balance. But having a closer look into the system internal imbalances show up: the text specifies changes in fluxes between atmosphere, oceans and land biosphere. Fluxes in this part of the carbon cycle that differ from zero by anthropogenic effect are seen as a disturbed balance. This anthropogenic imbalance of fluxes that increase the atmospheric pool causes global warming.

Table 2. Conceptions of the carbon cycle in global warming.

scientific conception	**Anthropogenic Imbalance**  "[In the figure] the natural or unperturbed exchanges […] among oceans, atmosphere and land are shown. […] While these fluxes vary from year to year, they are approximately in balance when averaged over longer time periods. [These] […] fluxes have become significantly different from zero […]." (figure and text: IPCC 2007, 501 ff.)
students' conceptions	**Man-made CO_2** "CO_2 is emitted into the atmosphere by burning coal and oil. Burning biofuel or wood does not emit CO_2. A normal atmosphere does not contain CO_2" (Danny, 18 yrs.). "The toxic CO_2 is emitted from fossil fuel by burning. Normal air does not contain CO_2" (Daniel, 18 yrs.).
	Natural vs. Man-made CO_2 "CO_2 emitted by burning cannot be removed from the air. It is chemical, not biological" (Emma, 18 yrs.). "Humans emit CO_2 by respiration. This CO_2 is captured by plants. It is a fact that the CO_2 emitted by burning has another structure than the CO_2 emitted by respiration. The CO_2 from burning cannot be captured again by photosynthesis" (Dave, 18 yrs.).

The conception man-made CO_2 shows that some students do not take CO_2 to be a natural component of the atmosphere, whereas the conception natural vs. man-made CO_2 implies that CO_2 emitted by burning has a different structure than CO_2 emitted by respiration. Although on a content level these conceptions are very different, scientists and students refer to the same schemata to think of the global carbon cycle: the already mentioned container schema (Figure 2) and the source-path-goal schema (Figure 9).

The source-path-goal schema is based on our locomotive experience of moving from A to B. An object (i.e., a person) moves from a starting point to a goal. The moving direction is defined by the start and the goal (Lakoff & Johnson 1999).

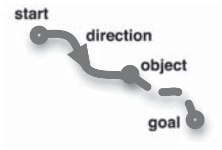


Figure 9. The source-path-goal schema.

As with the carbon, these two schemata are combined into a more complex ‘container-flow schema’. This container-flow schema is used to conceptualise the atmosphere, ocean and vegetation as containers enclosing carbon, which flows from one container to another (i.e. from fossil carbon to the atmosphere) via different routes (i.e. burning, respiration) (see Figure 10).

Terms like ‘into’, ‘flow between’, ‘flux’, ‘cycle between’ and ‘emission’ indicate the use of the container-flow schema. The figure taken from the IPCC report in Table 2 combines several containers and flows into a complex container-flow schema resulting in a typical model of the carbon cycle. Scientists and students differ in the use of the container-flow schema. Scientists ascribe climate change to imbalanced flow rates of carbon into the atmosphere and, thus, an increasing amount of content (CO_2) in the atmosphere. Students use the container-flow schema differently to understand climate change. They either attribute climate change to the mere existence of a content (man-made CO_2) or to the existence of a different content (man-made vs. natural CO_2) in the atmosphere (cf. Table 1). Scientists source climate change in the carbon flow, while students ascribe it to the existence of a specific content.

To understand climate change, the container-flow schema is accompanied by two more ideas: the distinction between natural vs. man-made and the balance schema (see Figures 11 and 12).

Metaphor analysis shows that the conceptions man-made CO_2 and natural vs. man-made CO_2 emerge from the judgement natural is good – man-made is bad. This issue resembles the fallacy of the appeal to nature (Moore 1996). On the basis of this judgement, the man-made CO_2 is attributed with devastating and detrimental properties, while an atmosphere without CO_2 or with only natural CO_2 is in an undisturbed, healthy state. While scientists mainly use the balance schema to denote the causes of climate change (from balanced to imbalanced carbon flows), students distinguish natural and man-made carbon content in the atmosphere as natural and man-made kinds of CO_2.

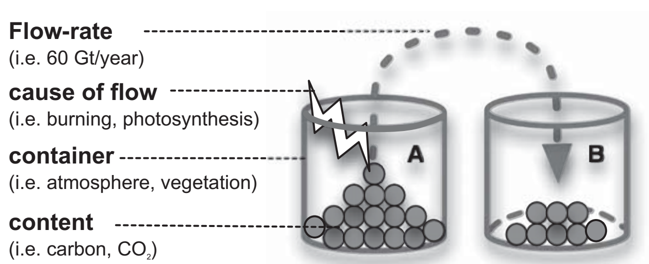


Figure 10. The container-flow schema.

The distinction natural vs. man-made describes what is natural and man-made. Normal or expected things are perceived as natural and abnormal things as man-made (Wachbroit 1994). This schema is often connected with the judgment *natural is good, man-made is bad.* Indicators are terms like *"man-made", "chemical"* or *"abnormal"*.

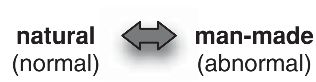


Figure 11. The distinction natural vs. man-made.

With our first attempts to stand up and walk, we experience the challenge to keep our balance. The balance schema is grounded in these experiences. This schema composes a logic where each change is followed by a counter-change (Lakoff 1987). Indicators are terms like "*balance*", "*equalise*" or "*compensate*". This schema is used to differentiate balanced carbon fluxes from unbalanced ones.

Figure 12. The balance schema.

Using the students' conceptions, we defined their learning demand on the carbon cycle by formulating three learning guidelines:

(1) See CO_2 as a natural compound of the atmosphere.
(2) Reflect the natural vs. man-made schema.
(3) Explain climate change by imbalanced carbon flows.

Guided by these principles, we developed different learning environments, which refer to the above-mentioned teaching guidelines. In the teaching experiments, two central learning environments were evaluated with regard to their effects on students' conceptual development. The learning environments are published in detail in Niebert (2009). The first environment aimed at modelling the carbon cycle in a container-flow model. For modelling, the students used a text about the carbon cycle and its man-made changes (see Figure 13).

Students were asked to explain the causes of climate change using the glass boxes and balls. We anticipated explanations based on unbalanced carbon flows into the atmosphere. The natural carbon flows between oceans/atmosphere and vegetation/atmosphere should be recognised as balanced. It should become clear that it is not the amount but the balance of the carbon flows that matters.

Students who adhere to the conception natural vs. man-made CO_2 read the following narrative adapted from 'The Periodic Table' by Levi (1975) published in Niebert (2009). In this narrative, Levi describes the carbon cycle as the cycling of a virtual carbon particle:

> Our character lies for hundreds of millions of years, bound to three atoms of oxygen and one of calcium, in the form of a limestone. In 1840 a man's pickaxe sent it on his way into the world of change …

While reading the story, the students were requested to model the carbon cycle presented in the story in the container-flow model. Students who used the natural vs. man-made schema were asked to reflect the schema against the backdrop of the

(1) Amount of carbon in different carbon stocks

Vegetation: 2.500 Gt; atmosphere: 750 Gt; oceans 38.000 Gt; fossil carbon: 10.000 Gt; 1 gigaton (Gt) = 10^{15} g, all data from IPCC (2007).

(2) The natural carbon cycle

About 90 Gt of carbon are emitted from the oceans into the atmosphere every year. The same amount of carbon flows back from the atmosphere into the oceans. Through photosynthesis, 120 Gt of carbon each year are captured and stored in land organisms, and 60 Gt of this carbon are released by respiration of plants and animals. The other 60 Gt are stored in the organisms. Once the organisms die, decomposers emit the carbon stored in the organisms.

(3) The anthropogenic carbon cycle

Through the burning of coal, oil and gas, 6.5 Gt of carbon are emitted from the stock of fossil carbon. An additional 1.6 Gt of carbon are emitted from the vegetation into the atmosphere by deforestation.

Figure 13. Modelling the carbon cycle in a container-flow model.

story and the model. We intended the story to communicate CO_2 as a natural compound of the atmosphere, identical in structure and quality regardless whether its source is burning or respiration. In the following two examples, we show how these learning environments can help students to achieve a scientifically adequate understanding of the carbon cycle.

3.3.1. Understanding the carbon cycle by materialising the container schema

In the following transcript of a teaching experiment, a student reconstructs her conceptions of the causes of climate change. Initially, she argues on the basis of the distinction between natural and man-made, with the mere existence of CO_2 as the cause of global warming (man-made CO_2). At the end of the teaching experiment, she argues on the basis of a balance schema with too much CO_2 (imbalanced carbon flows).

Interview at the beginning of the teaching experiment:

Interviewer: You said global warming is caused by CO_2. Please tell me where the CO_2 comes from.

Brenda: CO_2 is emitted by the industry, and it is not possible to reduce the CO_2 concentration to zero because of industrialisation. The only way it would be possible is when we use nothing but renewable energy.

At the beginning of the teaching experiment, Brenda referred to the concept of man-made CO_2. For her, carbon dioxide is produced solely by industrialisation, by burning fossil carbon. Her conception implies that using renewable energy exclusively would reduce CO_2 emissions to zero.

After modelling the carbon cycle:

Brenda: Carbon enters the atmosphere from the organisms by respiration, and photosynthesis captures it again. Carbon from the oceans enters the atmosphere, but the same amount goes back into the oceans. There is a natural, a balanced cycling. […] By deforestation, more CO_2 enters the atmosphere, and deforestation decreases photosynthesis because there are fewer trees. The carbon from deforestation stays in the atmosphere, because it cannot get down again. With the carbon from coal and oil, it is the same. It stays in the atmosphere, because not all CO_2 can be captured again; there is too much.

While modelling the carbon cycle, Brenda worked out the idea of a combination of balanced and imbalanced carbon flows and the cause of climate change. Modelling the carbon cycle with glass boxes and balls obviously helped Brenda to reconstruct her conceptions from the idea of man-made CO_2 to an anthropogenic imbalance in the carbon cycle. In her argument at the end of the teaching experiment, she traced global warming not to the existence of CO_2 but to too much CO_2. For Brenda, there is too much carbon emitted into the atmosphere to be captured by photosynthesis (see Figure 14).

3.3.2. Understanding climate change through changing ontology

Students who adhered to the conception of natural vs. man-made CO_2 read a narrative adapted from Primo Levi's 'The Periodic Table'. Dave is a student who reflects

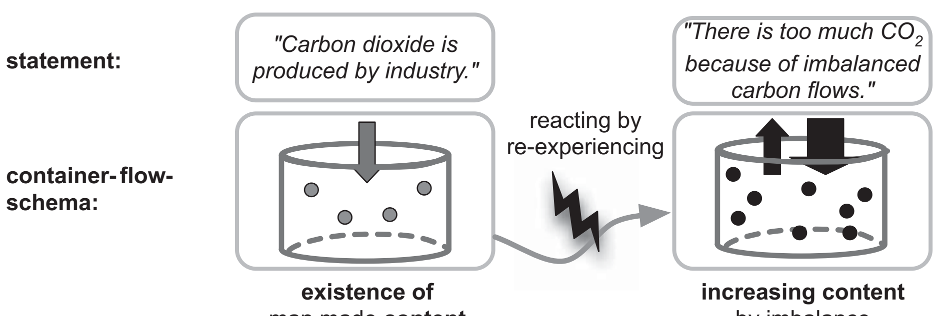


Figure 14. From man-made content to increasing content.

on his usage of the judgement *natural vs. man-made*, on which he bases his argument on climate change:

Interview at the beginning of the teaching experiment

> Dave: It is a fact that the CO_2 emitted by burning has another structure than the CO_2 emitted by respiration. Thus, the CO_2 from burning cannot be captured again by photosynthesis.

At the beginning of the teaching experiment, Dave reassured himself about the two kinds of CO_2 he employed in his argument on climate change. He argued the distinction natural vs. man-made CO_2.

While modelling the story

> Dave: My idea with the natural and the man-made CO_2 was humbug, because in the story, the carbon, which was burned, is captured again by photosynthesis. And if the tale is right, the idea of a natural and a man-made CO_2 with different properties must be wrong. CO_2 is CO_2. This is not the matter. The cause of emitting CO_2 – the burning – is man-made. The emission of CO_2 by respiration is natural.

After modelling the carbon cycle, Dave rejected the distinction between natural vs. man-made CO_2. The reason for this conceptual development is the idea that 'CO_2 is CO_2', mediated by the story, where CO_2 regardless if emitted from fossil carbon or by respiration is fixed again by photosynthesis. However, the distinction between natural vs. man-made played an important role in Dave's argumentation. After modelling the carbon cycle in the container-flow model, he no longer assigned the natural vs. man-made distinction to the matter (CO_2) but rather to the cause of the carbon flow (burning and respiration) (see Figure 15).

Moving balls from one labelled glass box to another is a materialised representation of the cognitive schemata employed in understanding the carbon cycle. By working with this representation, students re-experience the inherent structure of the schema and reflect on how they employ it in their effort to understand the carbon cycle.

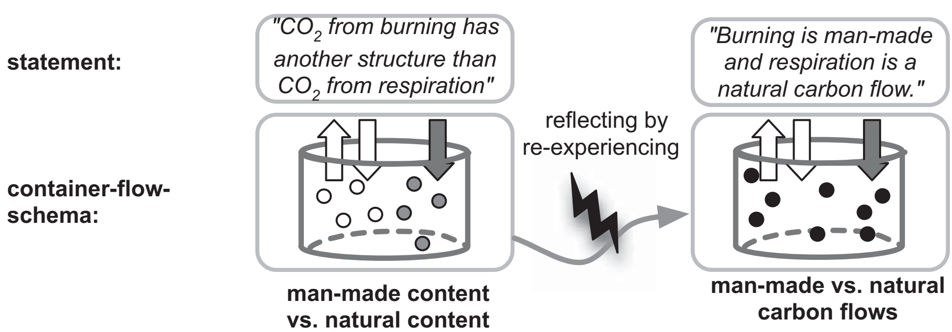


Figure 15. Reflecting on the use of the distinction natural vs. man-made schema.

4. Discussion and conclusions

So far, we have analysed metaphorical thinking on global warming in scientific textbooks and research reports, on the one hand, and interview data and video data of learning situations, on the other hand. We paid particular attention to the source domains of the metaphorical expressions to identify the experiential basis of understanding. Remarkably, students and scientists ground their understanding at the level of schemata on similar experiences. However, students and scientists differ considerably in the way the mapping from the source domain to the target domain is conducted. With regard to the experiential basis of the conceptions, we developed learning environments. Through evaluation in teaching experiments, we could track students' learning pathways. The learning pathways of students such as Max, Dave and Brenda showed that experientialism is very fruitful for analysing and facilitating students' conceptual development on climate change. In the following section, we will reflect on our cognitive linguistic approach of analysing the metaphorical understanding of a scientific topic from the perspective of research in science education. We will point out why analysing metaphors is not just 'nice to have' in science education but is a basis for both understanding and teaching.

4.1. Understanding climate change is metaphorical

The way we are as human beings restricts us to medium dimensions in interacting with our environment. This world, which Vollmer (1984) calls mesocosm, reaches from a 'blink' to 'a lifetime', from 'light as a feather' to 'heavy as an elephant', from a 'hair's breadth' to the 'horizon'. These dimensions explicitly refer to a human's sensory abilities and are perceivable and tangible. In contrast, macrocosmic structures such as the biosphere, the carbon cycle or the greenhouse effect are not part of the mesocosm because our cognitive apparatus was evolutionarily adapted to medium dimensions. With the macrocosm, we encounter an entity that is imperceptible, at least by means of everyday life.

Thus, metaphors 'as a bridge between experience and scientific concepts' are essential to understanding climate change. Interestingly, students' and scientists' conceptions of global warming refer to the same schemata, although they conceptualise them differently in the target domains 'carbon cycle' and 'greenhouse effect'. The container schema proves to be fundamental for thinking about carbon flows and the role of the atmosphere in global warming. For understanding global warming, the container schema is substantiated by other experiential conceptions such as the distinction between natural and man-made and the balance schema. While the balance schema is an indicator for scientific, or at least science-oriented, conceptions, the natural vs. man-made distinction can be conceptualised through different ontological entities: the substance (CO_2), the process (burning) or the cause of the process (burning by man).

4.2. Understanding macrocosm by experiencing mesocosm

As our interactions with our environment are restricted to medium dimensions, our basic concepts and schemata are of mesocosmic origin. We are confined to comprehending macrocosmic (as well as microscopic) phenomena in terms of mesocosmic concepts and schemata. This issue is one of the reasons climate change – and, often, science in general – is difficult to grasp.

Scientific understanding depends to a large degree on technologically extended perception, which enables us to gain insight into the microcosm and the macrocosm. Thus, scientific understanding depends largely on imagination. Schemata acquired in the mesocosm are used to comprehend phenomena in the micro- and macrocosm. Thus, scientific understanding can be traced back to experience in the mesocosm. This fact explains why even scientists refer to basic schemata such as the container schema, the balance schema or the source-path-goals schema to understand climate change.

This insight bears important consequences for instructional interventions. The experiences necessary for a scientific understanding must be provided, especially those that originate from the macrocosm. This finding is in accordance with Vosniadou and Ioannides' (1998) demand to provide 'meaningful experiences'. We organised meaningful experiences for our students by bringing their schemata into existence.

4.3. Understanding climate change by materialising schemata

Because both students and scientists refer to the same schemata as the source domain for their conceptions of climate change, learning about global warming can be facilitated by a reflection on the schemata.

Working with containers in coordination with information about the carbon cycle presented in a science-like and narrative context helps students to develop more pronounced scientific conceptions. After the teaching experiments, students are able to base their idea of a carbon cycle on more containers and on a change of carbon fluxes instead of on different types of CO_2.

Students referring to the conception natural and man-made CO_2 conceptualise the distinction between natural vs. man-made in a scientifically inadequate way onto the container-flow schema. Working with the container model and thereby reflecting on how to apply the distinction of natural vs. man-made to different parts of the model helps students reflect on their conceptions. Based upon the educationally reconstructed learning environments, a development can be seen from the scientifically untenable conception of man-made CO_2 via man-made carbon flow to the adequate conception of man-made cause of carbon flow and thus a change of the ontological category matter over process to cause. This result is in accordance with Chi (2008), who explained learning science as a categorical shift.

Investigating a CO_2-filled glass box or moving balls from one labelled glass box to another are both materialised representations of cognitive schemata employed in understanding climate change. By working with these representations, students re-experience the inherent structure of the schemata and reflect on how they employ it in their effort to understand the phenomenon.

This re-experiencing and reflecting helped students to understand the complex and abstract phenomenon of climate change. To this end, students need to work with learning environments that illuminate the schemata they employ in their endeavour to understand. Awareness of the schemata that shape conceptual understanding enables teachers to choose effective representations and to design learning environments that foster an understanding of science.

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Harald Gropengiesser is a professor of biology education and managing director of the Institute for Science Education at the Leibniz Universität Hannover. He taught biology and chemistry for 10 years at a Gymnasium (grammar school). His dissertation started an ongoing series of subject matter education studies based on the Model of Educational Reconstruction. He investigates students' and scientists' thinking based on experientialism and embodiment. He is a co-editor of the leading German university textbook for biology education.

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