Chapter 37
"*CO_2 Causes a Hole in the Atmosphere*": Using Laypeople's Conceptions as a Starting Point to Communicate Climate Change

Kai Niebert and Harald Gropengießer

Abstract Translating public concern for global warming into effective action requires knowledge about the causes and risks of climate change. The aim of this study is a theory-guided analysis of everyday and scientific conceptions of global warming. These conceptions will be the basis for the design of communicating strategies in a separate study.

Framed by the model of educational reconstruction, scientific concepts of global warming were compared with everyday conceptions that were identified in interviews and a re-analysis of empirical studies. The analysis of conceptions of climate change based on the theory of experientialism (Lakoff and Johnson, Philosophy in the Flesh. The Embodied Mind and Its Challenge To Western Thought, 1999) shows that laypeople and scientists refer to the same schemata: the use of the container-flow schema is omnipresent in conceptions on the global carbon cycle as well as in conceptions of the radiative equilibrium between earth and space. To explain the causes of global warming three principles were found: global warming by (a) an imbalance in the global carbon cycle, (b) man-made carbon dioxide, and (c) natural vs. man-made carbon dioxide. Laypeople explain the processes leading to global warming either through warming by more input or warming by less output.

Keywords Carbon dioxide · Climate change · Communication · Education · Everyday conceptions · Greenhouse effect

Introduction

The enhanced greenhouse effect leading to global warming is one of the greatest challenges facing humankind in the twenty-first century (IPCC 2007). Translating public concern for global warming into effective everyday action requires knowledge about the causes and risks of climate change (Bord et al. 2000; UNCED 1992).

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The aim of our study is an evidence-based and theory-guided identification of key aspects in understanding global warming. Based on the key aspects identified, educationally reconstructed communication guidelines will be developed.

A wide range of studies show a confusion among laypeople of causes and mechanisms leading to global warming with other ecological phenomena, such as the depletion of the ozone layer. Interestingly, this confusion is constant over age and nationality: Swedish 10-year-old pupils hold the same everyday conceptions of global warming as English pre-service teachers or American laypeople (Bord et al. 1998; Bostrom et al. 1994; Boyes and Stanisstreet 1997; Boyes and Stanisstreet 1993; Boyes et al. 1999; Christidou and Koulaidis 1996; Read et al. 1994). Additionally, these conceptions are very resistant to conceptual change (Hansen 2005). This study analyses the sources of students' alternative conceptions to explain the origins of these conceptions and what prevents students from using more scientific conceptions to explain the causes and mechanism of global warming.

The main focus of our study is the interpretation of students' and scientists' conceptions of aspects of global warming, such as the greenhouse effect, and the emission and fixation of greenhouse gases. It draws on the perspective of experientialism (Lakoff and Johnson 1980; 1999), which contributes to an improved understanding of the sources of conceptions of climate change.

Theoretical Framework and Key Objectives

Several studies (Bord et al. 1998; Bostrom et al. 1994; Boyes and Stanisstreet 1993, 1997; Boyes et al. 1999; Christidou and Koulaidis 1996; Read et al. 1994), have investigated school students' and adult lay peoples understandings of concepts related to global atmospheric change, such as the greenhouse effect or ozone layer depletion. These studies either state explicitly that they are pre-instructional or do not to follow any specific global atmospheric change instruction. The findings of these studies indicate that students often hold conceptions about global atmospheric change that differ from scientific knowledge. Furthermore, studies by Österlind (2005) and Jeffries et al. (2001) show that those everyday conceptions of climate change are resistant to conceptual change even after instruction given by school or media. Our study aims to understand why some everyday conceptions are so common and what makes them resistant to conceptual change.

The theoretical framework of this investigation relies on two different but interdependent theories. The moderate constructivist epistemology (Duit and Treagust 1998) states that learning is a construction of individual conceptions. This epistemological orientation concerns the understanding of students' perspectives as well as the interpretation of the scientific content. From this perspective, everyday conceptions are not seen as obstacles to learning but as starting points for learning and mental instruments to work with in further learning.

An important empirical finding emerging from linguistic studies (Lakoff 1987; 1991; Lakoff and Johnson 1980, 1999) is that many concepts might not be understood literally but metaphorically in terms of another domain of knowledge. An important related proposal is that the understanding of abstract concepts is ultimately grounded in experiential image schemata (Lakoff and Johnson 1999). Lakoff and Johnson (1980) identified metaphorical schemata, which transfer understanding from an experience based domain into an abstract domain: an example is the metaphor *"Argument is war"*, which is implicit in the following sentences listed by Lakoff and Johnson: "Your claims are indefensible." "He attacked every weak point in my argument." "If you use that strategy, he'll wipe you out." Rather than view such sentences as simply a matter of isolated instances of a figurative language, Lakoff and Johnson pointed out that they reflect a systematic way in which arguments are conceptualized in terms of our understanding of physical conflict: attacking and defending, the success or failure of which will result in gaining ground or retreating, winning or losing, and so forth. The claim is that our understanding of physical conflict organizes how we talk and think about arguments.

The cognitive linguistic theory of experientialism (Gropengießer 2007; Lakoff and Johnson 1980; Riemeier and Gropengießer 2008) describes how we employ metaphors and analogies to project understanding from an experience-based source domain to an abstract target domain. Experientialism guides us to gain an insight into the sources of students' everyday conceptions.

Constructivism and experientialism are used to interpret students' everyday conceptions of global warming to gain a deeper understanding of their ways of thinking and to explain their perspectives. These findings provide an insight into individual ways of thinking and how everyday conceptions foster or hinder students' conceptual development. Based on this framework, the study deals with three research questions:

1. What conceptions do students and scientists employ in explaining biological aspects of global warming?
2. What different and shared views can be drawn between students' and scientists' conceptions of global warming?
3. Which concepts can foster or hinder conceptual development in understanding global warming?

Research Design and Method

The research design is shaped by the Model of Educational Reconstruction (Duit et al. 2005). Within this design, scientists' and students' conceptions are compared in order to develop effective teaching and learning activities (cf. Fig. 37.1). Scientists' conceptions are extracted from different scientific textbooks (Campbell and Reece 2002; Houghton 2002; Schönwiese 2003; Smith and Smith 2006) and the most recent IPCC Report (IPCC 2007).

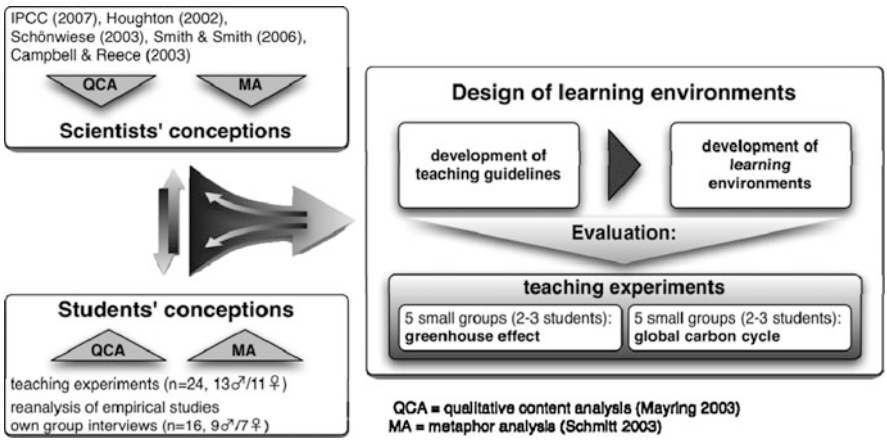


Fig. 37.1 Research design – the model of educational reconstruction

Students' conceptions of global warming are derived from a re-analysis of empirical studies on everyday concepts of global warming (Bostrom et al. 1994; Boyes and Stanisstreet 1992; Ekborg and Areskoug 2006; Koulaidis and Christidou 1998), our own interview study and an interventional study.

The interview study was conducted with 16 students (18 years old; 9 male, 7 female) from different grammar schools in Hannover (Germany) using semi-structured group interviews (Cohen et al. 2007) with two students per interview. The students were taking advanced courses in biology and had a medium proficiency level in the subject (German school grades between 2 and 4, equating approximately to English grades B to D). In the interventional study, 24 students (18 years old; 13 male, 11 female) from the same population as the interview study attended university for teaching experiments. The conceptions of the students in the interventional study were taken from an initial interview phase; the effects of the interventions are analysed in a separate study. The problem-centred interviews in the interview study, as well as the initial interviews in the teaching experiments, were guided by students' conceptions. Thus, not all interviews contained sequences to all parts of this study: Some interviews focused on the greenhouse effect (12 students), some on the global carbon cycle (12 students), and some on both (16 students).

Students' and scientists' conceptions are analysed using qualitative content analysis (Mayring 2002) and metaphor analysis (Schmitt 2005). In the qualitative content analysis, a category system was developed in the following steps: (1) transcription of the interviews and rewriting the texts, (2) arrangement of statements, (3) explication of the conceptions, and (4) summary of the categories. The metaphor analysis (Schmitt 2005) 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, which has or can have more than one meaning. Inthe first step, (1) we identified all metaphors in the material and (2) chose the ones crucial for the

understanding of climate change. Later, we arranged all metaphors with the same target and source domains (3) to describe the metaphorical principles used by the students and scientists. The results of the metaphor analysis were integrated into the explication of the conceptions during qualitative content analysis.

Based on the results of the educational reconstruction of global warming, learning activities are evaluated in a separate intervention study.

Results

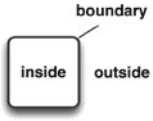
A re-analysis of empirical studies and data from our interview study shows that students' conceptions of the causes and mechanisms of global warming are different from scientists' conceptions. In the following sections, the conceptions of both are presented and interpreted, guided by the theory of experientialism.

Conceptions of the Causes of Global Warming

In our interview study, CO_2 is cited as being the most important cause of global warming by both scientists and students. Thus, the focus of our interviews was on the emission and fixation of CO_2 in the global carbon cycle. Our results underline the findings of Hildebrandt (2006), who has shown that learners' conceptions of the biogeochemical processes of the global carbon cycle are different to scientists' conceptions. Metaphor analysis shows that students as well as scientists refer to a container-flow schema. In this schema, carbon is stored in different containers (e.g. fossil carbon, land, oceans, atmosphere) connected by bidirectional flows of carbon caused by varying processes (e.g. photosynthesis, burning, respiration). Thus, the container schema and the source-path-goal schema (Lakoff and Johnson 1999) are combined into the larger complex container-flow schema (cf. Fig. 37.2). In the following section, this schema is used to interpret conceptions of carbon flows.

Scientists' Conception: Global Warming by Imbalanced Carbon Cycle

Climatologists (Houghton 2002) and ecologists (e.g. Smith and Smith 2006) use the container-flow schema in different ways. While the climatologists focus on the location of the reservoir (e.g. lithosphere, atmosphere), ecologists highlight the stored carbon compound (organic vs. inorganic). Both views on the global carbon cycle are complementary in the explanation of the causes of global warming (Fig. 37.3).

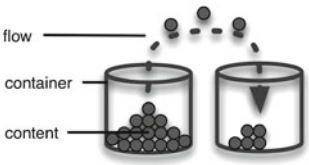


A container has an inside and an outside, divided by a boundary. Thus a substance can be inside or outside a container.

Container schema

When something changes its position it has to move from a source via a path to its goal.

Source-path-goal schema



If there is a substance in a container it can *flow* from its *source* in *container A* to its *goal* in *container B*.
In describing the global carbon cycle scientists use a special logic of the container-flow schema: the carbon can be just in one container or the other, but never outside both containers. Being out of one container means being in another container.

Container-flow schema

Fig. 37.2 Logic of the container-flow schema

There is a relative balance between the containers *land biosphere*, *oceans*, and *lithosphere*, on the one hand, and the *atmosphere,* on the other. In long-term scales the same amount of carbon is cycling between the containers.
Industrial processes like the burning of fossil fuels empty the container *fossil carbon* into the container *atmosphere*. Additionally the container *biosphere* is emptied into the *atmosphere* by deforestation.
The additional amount of carbon can only partly be withdrawn from the atmosphere into the *oceans* and the *land biosphere*.

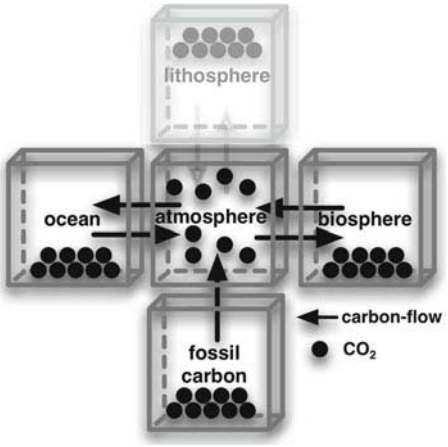


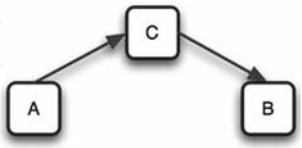
Fig. 37.3 Imbalance in the global carbon cycle

In the context of global warming, scientists focus on the atmosphere and its carbon flows. For the sake of clarity and brevity, all flows between the other carbon containers (e.g. solution of minerals in oceans) as well as the container *lithosphere* with very small rates of carbon flows are excluded here.

Scientists use different terms to describe the global carbon cycle. While ecologists describe a flow of *carbon* between the reservoirs, climatologists describe a flux of *carbon dioxide*. So the quality of the content flowing between the containers differs between the scientific disciplines. Climatologists concentrate on a part of the carbon cycle and do not treat the whole cycle. Metaphor analysis shows the different usage of the container-flow schema by climatologists and ecologists (Fig. 37.4).

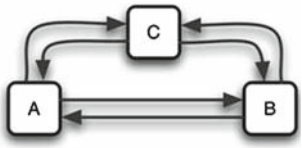
The scientists' conception is based on the schema of a natural balance in the global carbon cycle, which is disturbed by processes such as the burning of fossil

"Carbon dioxide is emitted by the burning of fossil fuels. […] CO_2 can be withdrawn from the atmosphere by photosynthesis." (Houghton, 2002)



With the description of sources and sinks for carbon dioxide, a starting point and a destination of the container-flow schema are set.

"Carbon cycles through the terrestrial ecosystem" (Smith & Smith, 2002).



The description of a circulation of carbon assumes a variable assignment of the starting points and destinations of carbon. Every reservoir contains carbon temporarily and can act as a source or a sink.

Fig. 37.4 Schemata of carbon flow

carbon or deforestation. Thus, we named this thinking pattern global warming by imbalanced carbon cycle.

Everyday Conception: Man-Made Carbon Dioxide

In some students' conceptions CO_2 is a man-made gas causing climate change:

> CO_2 is produced by the burning of coal and oil. […] Burning biofuel or wood does not emit CO_2, because they are climate-friendly. […] CO_2 stays in the atmosphere and cannot be removed again
> (Dirk, 18)

> CO_2 gets into the atmosphere through the burning of oil and petrol. To destroy the CO_2 we have to shoot little molecules into the atmosphere.
> (Jakob, 18)

Students with this conception think that the only source of CO_2 is the burning of fossil fuel. Al Gore's demand, *"Reduce your CO_2 emissions to zero"*, (Gore 2006) is rejected by the students not on physiological grounds (e.g. the need for respiration) but because *"even without industry and cars we have to make a fire to cook and have a warm home"* (Emma, 18). In this conception, natural processes such as the physiological or biogeochemical fixation and emission of carbon (respiration, photosynthesis, solution, dissolution in oceans) are either not mentioned or rejected. The structure of this conception is presented in Fig. 37.5.

The emission of CO_2 is connected with the process of burning and the substance that is burned. In this conception, students argue that carbon dioxide is detrimental to the climate. Furthermore, they argue that fossil fuel is hostile to the climate, while renewable fuels are not detrimental to the climate. So they conclude that fossil fuel does emit CO_2, while renewable fuels do not emit CO_2 (Fig. 37.6).

Carbon dioxide is seen as something unnatural, chemical, or toxic, which is underlined by statements like *"normal air has no carbon dioxide"* (Daniel, 18) or *"carbon dioxide is a toxic gas"* (Jacob, 18).

The burning of fossil carbon emits CO_2.
Organisms do not emit CO_2.
CO_2 cannot be removed from the atmosphere.

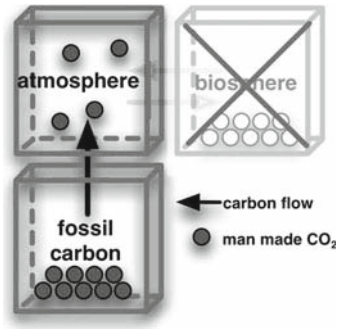


Fig. 37.5 Man-made carbon dioxide

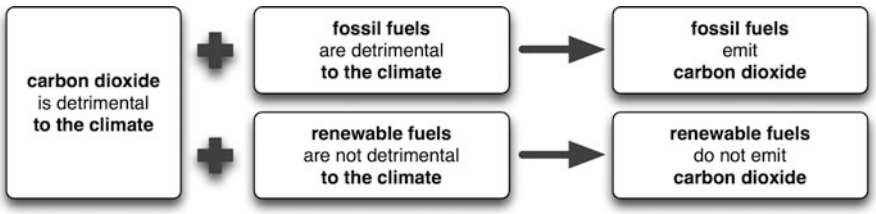


Fig. 37.6 Two attribution patterns for the emission of CO_2

Everyday Conception: Natural Versus Man-Made Carbon Dioxide

A typical conception of the causes of global warming is the emission of different sorts of CO_2:

> CO_2 emitted by the burning of oil cannot be removed again from the atmosphere because it rises higher than CO_2 from respiration.
> (Dirk, 18)

> CO_2 emitted by burning cannot be removed from the air. It is chemical not biological.
> (Emma, 18)

Students who distinguish between *"natural and man–made carbon dioxide"* (Fig. 37.7) refer to physiological processes (respiration and photosynthesis) but do not contextualize them in climate change terms. Their knowledge of physiology (CO_2 emitted by respiration) and ecology (CO_2 emitted by burning of fossil carbon) is used in parallel but is not connected. The different sources of carbon dioxide lead to the conception of different kinds of CO_2 with different properties. Metaphor analysis validates this interpretation. Like the scientists, the students also use the container-flow schema to explain the emission of carbon dioxide. But the students' containers hold different kinds of carbon dioxide: natural and man-made CO_2. The conception *flow of man-made carbon dioxide* is – as in the conception *man-made carbon dioxide* – conducted by a one-way metaphor: man-made CO_2 can only flow from the container *fossil carbon* to the container named *atmosphere*, and there is no way back.

1. The burning of fossil carbon emits CO_2.
2. Organisms emit CO_2.
3. CO_2 emitted by organisms can be removed from the atmosphere.
4. CO_2 emitted by burning cannot be removed from the atmosphere.

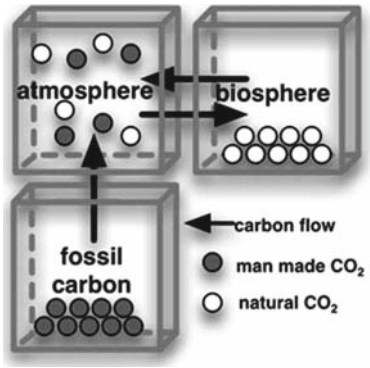


Fig. 37.7 Natural vs. man-made CO_2

Comparison of the Conceptions of the Causes of Global Warming

The comparison of students' and scientists' conceptions of the biogeochemical origins of global warming shows differences in the use of the container schema and the content of the containers. The only concept used by both scientists and students is the emission of carbon dioxide through the burning of fossil carbon. The majority of the interviewed students (20 of 28) argued that the carbon dioxide produced by burning is bad and detrimental in general. Eight students were able to refer to the scientific conception of a relative imbalance in the global carbon cycle (without mentioning the lithosphere as a carbon container) (Table 37.1).

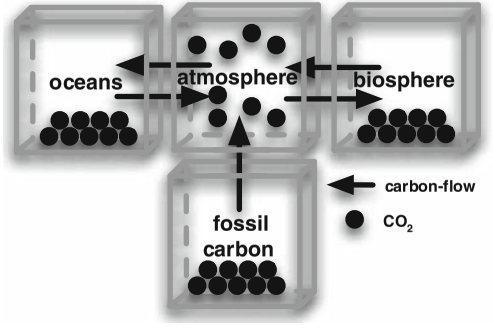
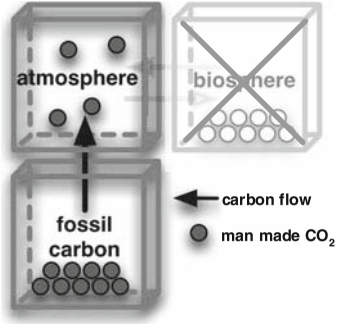
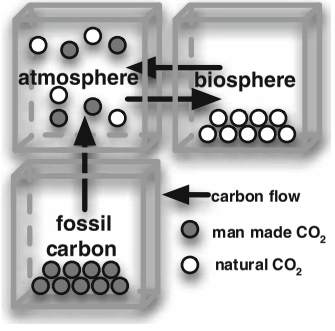
Scientists' conception of an imbalance in the global carbon cycle is based on the idea of a natural balance in the carbon cycle. This idea was criticized by Kattmann (2008), who argues that the actual concentration of O_2 – and thus the concentration of CO_2 – is a product of a series of imbalances and not of a long-lasting balance: the first atmosphere about 4.5 billion years ago did not contain any O_2 but about 500 times more CO_2 than the present atmosphere. If the atmospheric concentration of CO_2 had been balanced at all times, CO_2 and O_2 concentration would not have changed and life on earth would not have evolved as it did.

To describe the carbon flows, two different metaphorical concepts were found in students' and scientists' conceptions: *"Burning is producing"* (*"CO_2 is produced by the burning of fossil fuel"*) and *"Burning is emitting"* (*"Carbon is emitted by the burning of fossil fuel"*). These two concepts show different perspectives on the global carbon cycle: while the first concept focuses on the conversion of hydrocarbons into CO_2, the second concept emphasizes the flow of carbon from one container to another and thus on the balances in the global carbon cycle.

Conceptions of the Mechanisms of Global Warming

Different conceptions of global warming were identified in our study. Experientalism shows that similar to carbon flows, students and scientists explain the mechanisms of

Table 37.1 Conceptions of the causes of climate change

Imbalanced carbon cycle	Man-made CO_2	Natural vs. man-made CO_2
Frequency: 8 of 28 students[a] and scientists	Frequency: 8 of 28 students[a]	Frequency: 12 of 28 students[a]
		
The burning of fossil carbon emits more CO_2 than oceans and biosphere can capture	The burning of fossil carbon emits detrimental CO_2	The burning of fossil carbon emits man-made CO_2, while respiration emits natural CO_2

[a]Due to the research design, not all students argued on all topics discussed in this paper; 28 of the 40 students elaborated their conceptions on the emission and fixation of CO_2

global warming with a container-flow schema. Atmosphere and earth are seen as a container, where energy is irradiated by the sun and reradiated by the earth again.

Scientists' Conception: Warming by Warming Blanket

An analysis of scientists' conceptions (Houghton 2002; Schönwiese 2003) of the mechanisms of global warming shows that scientists differentiate between the atmospheric phenomenon of ozone depletion, which leads to the intensified penetration of UV rays to Earth, and the intensified greenhouse effect which leads to global warming. Both phenomena are different in their temporal, structural and regional impacts (Table 37.2).

Scientists conceptualize the processes leading to global warming as follows (Fig. 37.8): (1) Greenhouse gases are in a first approximation evenly distributed in the atmosphere. (2) Special molecular properties enable greenhouse gases to absorb infrared radiation very effectively. (3) The intensified emission of greenhouse gases leads to an enhanced absorption of radiation. (4) Greenhouse gases emit heat in all directions and the emission to the earth adds up to the direct radiation from the sun and (5) the lower atmosphere warms up.

Metaphor analysis shows that scientists are referring to a container schema and a balance schema, where earth and atmosphere are represented as a container and the sun sends a constant amount of energy into the container. In the case of the natural greenhouse effect there is a radiation equilibrium, i.e. the same amount of energy that gets into the container leaves it by re-radiation. With every emitted greenhouse gas molecule, more outgoing radiation is captured and a new equilibrium arises. Viewed from outside the container, a constant amount of energy flows into the container, but the output is reduced until a new equilibrium is reached. The atmosphere with greenhouse gases acts like a thick warming blanket, which insulates the earth.

Table 37.2 Ozone depletion and greenhouse effect

	Ozone depletion	Greenhouse effect
Projection	Decreasing until the year 2100	Increasing until the year 2100
Altitude	Ozone layer at 35 km altitude	Greenhouse gases in the whole atmosphere
Process	Decreased absorption of UV radiation	Increased absorption of IR radiation
Effect	Regional	Global
Impacts	Skin diseases, skin cancer	Heat diseases, change in ecosystems

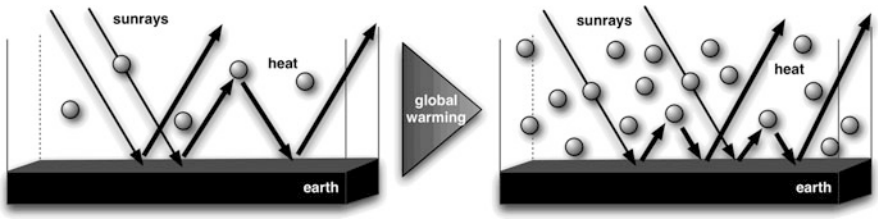


Fig. 37.8 Scientific conception: the warming blanket

Students' Conception: Warming by Holes in the Ozone Layer

The conception of global warming being caused by holes in the ozone layer is a typical conception held by students:

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

> The ozone hole is getting bigger, which is caused by industrial emissions. More sunrays enter the atmosphere and warm the earth. They cannot leave the atmosphere again because the heat is captured between the ozone layer and earth.
> (Nanni, 18)

With this conception, students imagine the mechanisms causing global warming as follows (Fig. 37.9): (1) Normally the ozone layer reflects some sunrays back into space. (2) CO_2 causes a hole in the ozone layer, and (3) sunrays penetrate the layer through the hole and (4) warm the earth. In a variant of this way of thinking, students imagine that (5) infrared radiation is captured between the earth's surface and the ozone layer.

In our study, 11 of 16 students expressed the conception of more sunrays passing through a hole in the *atmospheric protection shield ozone layer*. Metaphor analysis indicates students' use of the container schema to describe the mechanisms of global warming. Compared to the radiative equilibrium where input equals output, the conception *warming by hole in the ozone layer* is based on a *warming by more input*.

Students using this conception do not distinguish between long-wave and short-wave radiation. From an experientialist point of view, this is not surprising because we experience the sunrays as warming us directly – the more there are, the warmer it is (see also Hansen 2005).

The hybridization of the ozone problem with the greenhouse effect is a well described finding in science education research (e.g. Ekborg and Areskoug 2006; Koulaidis and Christidou 1999). The concept of a perforated *atmospheric protection shield* combined with the concept of an *atmospheric warming blanket* leads to a quite simple idea: *the atmosphere warms up, because more heat gets in.*

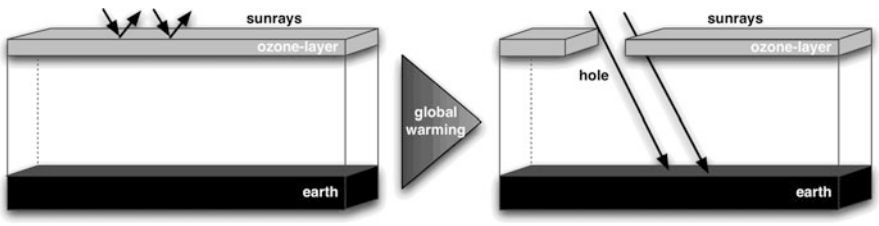


Fig. 37.9 Students' conception: Warming by holes in the ozone layer

Students' Conception: Warming by Greenhouse Effect

The greenhouse effect is one of the students' principles for explaining climate change:

> 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 is reflected between the greenhouse layer and the earth.
> (Claudia, 18)

> CO_2 hinders the visible light coming to earth from going back to space again and reflects the light back to earth. So the earth is warming.
> (Jürgen, 18)

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. The greenhouse gas layer works like a *"perforated mirror, which lets some heat back to space. [. . .] CO_2 closes the holes in the mirror and no more heat can escape to space."* (Jakob, 18) (Fig. 37.10).

This conception is similar to the greenhouse effect communicated in the media or in school books. The central element of this conception is a layer of greenhouse gases, which acts as a barrier. By reflection of heat radiation between the layer and earth, the heat in the atmosphere is "captured". The basic idea is: *the earth warms up, because less heat gets out.*

Comparing Jürgen's and Claudia's conceptions, one important difference can be found: while Claudia differentiates between sun's rays and heat rays, Jürgen just argues on the level of sun's rays. The latter does not use the concept of energy transformation in the process of absorption sun's rays and the re-radiation of heat rays.

Students' Conception: Warming by Pollution

Furthermore, some students hold simple and straightforward conceptions of the causes of global warming. For them "*the rubbish, exhaust emissions and pollution lead to climate change*" (Diana, 18 years) In this pollution concept students sum up all environmental problems and project them onto global warming. The concept *pollution causes global warming* names a cause but does not explain the mechanism leading to global warming.

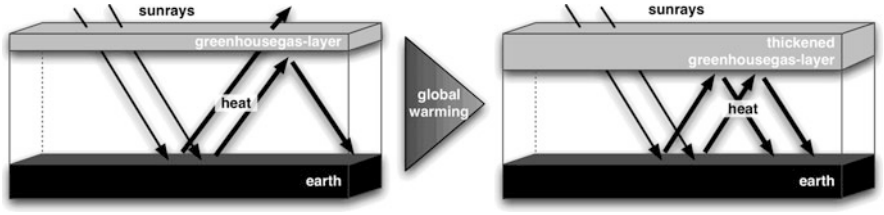


Fig. 37.10 Warming by greenhouse effect

Comparison of Conceptions of the Mechanisms of Global Warming

In Table 37.3, the conceptions of the mechanisms of global warming are compared. In addition to the different schemata used to describe reasons for global warming, there is one main difference between students' and scientists' conceptions. Students think on a macroscopic level (*reflection on layers*) while scientists argue on a microscopic level (*absorption by molecules*). This is not a surprising finding, as we experience our life world as a macroscopic one.

The comparison shows three fundamental schemata of the mechanisms of global warming: *"Earth warms up, because more heat gets in"*, *"Earth warms up, because less heat gets out"* and *"Earth is warming in a dynamic equilibrium"*. The conceptions differ in the mentioned structures (ozone layer, greenhouse gas layer, whole atmosphere) and the mechanisms (reflection vs. absorption/emission).

Metaphors of Global Warming

The metaphor analysis shows different receptions of the terms used to communicate global warming. Especially the terms *"warmth"* and *"heat"* are used in different in varying contexts (Table 37.4):

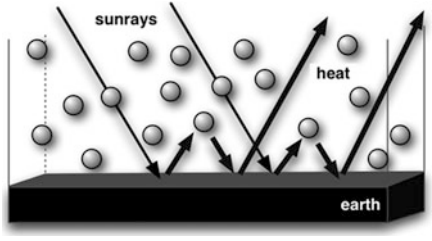
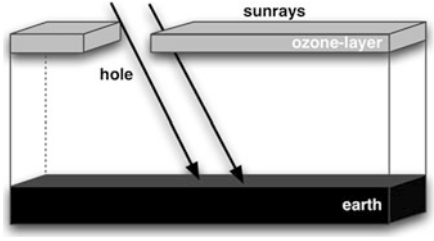
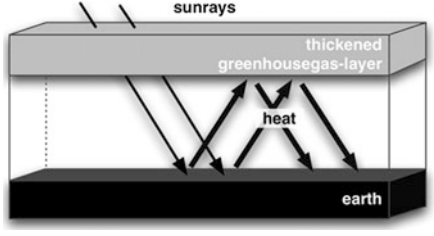
In several interviews, we found that students hold two different conceptions in parallel, using different terms in connection with these conceptions. While in the students' expressions the term *"warmth"* is connected to positive attitudes and convenient anticipations of the impacts of global warming like a warmer climate (*"I like it…"*, *"…would be very nice…"*), the term *"heat"* is connected to negative emotions and dramatic consequences (*"…would be dramatic"*, *"stop … immediately"*).

Even in the scientific literature, the terms *"warmth"* and *"heat"* are used in different contexts: the IPCC used the term *"warmth"* to describe the causes of global warming in a neutral way, while the use of *"heat"* can be found in the description of the (mostly negative) impacts of global warming.

These different conceptions connected to global warming can be ascribed to the different receptions of the terms in everyday life: the term *"warm"* has a positive connotation which expresses in different metaphorical and literal wordings as "*warm*-hearted", "to grow *warm*", "to feel *warm* and fuzzy" or "I feel *warm*". On the other hand the term *"heat"* has negative connotations like "scorching *heat*", "to beat the *heat*", "to swelter in *heat*".

Bibliographies describe the term heat as a *"very strong and unpleasant warmth"* (Duden 2002). Thus, the term heat is a concretizing, strengthening comparison of the term warming, which is used literally to describe an uncomfortable, very strong warming in everyday issues like the weather, and metaphorically for abstract issues like emotions or the climate which cannot be experienced directly.

Table 37.3 Conceptions of the mechanisms of global warming

Warming blanket	Ozone hole	Greenhouse effect
Frequency: Scientists	Frequency: 16 of 28 students[a]	Frequency: 12 of 28 students[a]
		
Earth warms up in a dynamic equilibrium.	Earth warms up because more heat gets in	Earth warms up because less heat gets out

[a]Due to the research design not all students argued on all topics discussed in this paper; 28 of the 40 students elaborated their conceptions of the mechanism on global warming

Discussion and Implications for Communication of Climate Change

In this investigation, different conceptions of climate change were found and interpreted using the theory of experientialism. While the nature of the samples studied here limits their generalizability, by allowing respondents to structure and define their own responses, we can offer a clearer perspective on how people conceptualize and describe these issues than is possible with a conventional large-scale study, with a uniform wording of potentially unfamiliar questions and responses. Different studies show that the everyday conceptions analysed in this article can be found in samples ranging from school students in the US and Europe (Koulaidis and Christidou 1998; Lee et al. 2007), university students (Jeffries et al. 2001), and adult laypeople (Bostrom et al. 1994; Sterman and Sweeney 2007). Additionally, the analysis of the conceptions in this study showed a saturation of data: no new conceptions were found. These two findings indicate the ability to generalize our findings to a wider population of laypeople.

Analysis of the conceptions regarding the *causes of global warming* reveals the use of container-flow schemata to explain the exchange of carbon between different spheres. A detailed analysis of the schemata shows differences in the number of the containers and the content of the containers. The thinking pattern *man-made carbon dioxide* shows that some students do not count carbon dioxide as a natural component of the atmosphere, while the thinking pattern *natural vs. man-made carbon dioxide* implies that different containers contain different kinds of carbon dioxide. In the latter conception, students are not able to draw a connection between their physiological and ecological knowledge of the emission and fixation of carbon dioxide. Metaphor analysis shows the conceptions *man-made carbon dioxide* and *natural vs. man-made carbon dioxide* emerging from the schema *natural is good – man-made is bad*. In this deeply rooted cultural schema, nature and its natural processes are perceived as something natural and good, while man-made, artificial processes lead to negatively perceived impacts (Niebert 2008). This resembles the fallacy of the *appeal to nature*. Based on this schema the *man-made* CO_2 is considered to possess devastating and detrimental properties, while an atmosphere without CO_2 (in the conception *man-made carbon dioxide*) or only with natural CO_2 (in the conception *natural vs. man-made carbon dioxide*) is in an undisturbed, healthy state.

From the perspective of a moderate constructivism, these everyday conceptions can be used as a starting point to communicate more science-oriented conceptions. By uncovering the – mostly unconsciously – used schemata for our thinking on global warming, communication strategies which focus on the following scheme might be fruitful: (1) Give students access to their conceptions, i.e. *uncovering the used schema*; (2) discuss the consequences of the domain specific use of the schema, i.e. *what is man made:* CO_2 *itself or the flow?* (3) Help students to reconstruct their conceptions, i.e. from *man-made and natural* CO_2 to the scientific

Table 37.4 Terms of global warming

Warmth	Heat
"I like it, that the earth is warming by 2–6°C." (Emma, 18)	"[. . .] a heating of the atmosphere by 3°C would be dramatic." (Emma, 18)
"A warmer climate would be very nice." (Jacob, 18)	"We have to stop emitting CO_2 immediately, because it heats up the earth." (Jacob, 18)
"Main cause of global warming is the anthropogenic emission of greenhouse gases." (IPCC 2007)	"Drought catastrophes will be one consequence of heating of the climate." (IPCC 2007)

concept *man-made and natural cause of carbon flow* by reflecting on and experiencing their mental model.

The aim of learning activities for the global carbon cycle should be (a) to communicate CO_2 as a natural component of the atmosphere, (b) to emphasize the equal structure of CO_2 from burning processes and physiological processes, (c) to discuss the conception of the global carbon cycle in a container-flow schema and (d) to discuss the increasing CO_2 concentration in the container atmosphere as an interaction with the other carbon containers. Teaching the global carbon cycle on the level of carbon and not on the level of different carbon compounds (CO_2, CO_3^{2-}, HCO, etc.) seems to be a fruitful basis for the guidelines discussed above. Thus the concept *burning is emitting* would be more appropriate to explain the carbon flows leading to global warming than the concept *burning is producing*.

The analysis of the thinking patterns about *mechanisms of global warming* reveals that students already have science-orientated conceptions. These are either hybrids of different ideas about atmospheric phenomena (*depletion of ozone vs. greenhouse effect*) or a simplified description of atmospheric processes (*reflection of radiation, greenhouse gas layer).* Ekborg and Areskoug (2006) described five thinking patterns laypeople use to describe the mechanism of global warming in their relation to a climatologist's point of view. From the perspective of experientialism we were able to reduce these five thinking patterns to two: *warming by more input* and *warming by less output*. Life-world experiences can be linked to either of the two following conceptions. *warming by more input* means turning the heater up to warm a room or to heat an oven to cook some food. *Warming by less output* is more difficult to understand, because one needs to understand that there is already heat inside a container (room, bed, etc.), which has to be captured by insulating the container (insulation layer for house, warming blanket for bed). To understand the idea of an insulating layer, one has to understand the container-flow schema, because warming by less output needs a continuous flow of energy into a container, thus producing an imbalance in the equilibrium by keeping the energy from going out again.

Based on our study we can supplement the recommendations Koulaidis and Christidou (1998) described with a set of experiences students need in order to understand the greenhouse effect. The aim of teaching sequences about global warming should be (a) to arrange a conceptual change from *"The earth is warming because more heat gets in"* via *"The earth is warming because less heat gets out"*

to *"The earth is warming in a dynamic equilibrium"*; (b) to show that absorption and emission are the elementary processes of the greenhouse effect and not reflection; (c) ozone depletion and the greenhouse effect are two phenomena that differ regionally, temporally, and structurally; and (d) to show that sunlight consists of different forms of radiation (e.g. visible and heat radiation).

In many school books, popular science magazines, and in the media, the greenhouse effect is communicated with a *greenhouse gas layer* and a *reflection of heat between the layer and earth's surface*. These scientifically incorrect and misleading representations can lead students to confound the *"greenhouse gas layer"* with the *"ozone layer"*. Additionally, the linguistic analysis of the terms used in communicating atmospheric phenomena shows the linguistic closeness of the German term *Treibgas* (e.g. CFCs), meaning propellant gases, and *Treibhausgas* (e.g. CO_2, CH_4, N_2O), meaning greenhouse gas. The use of *klimaaktive Gase* (climate active gases) instead of *Treibhausgas* is clearer.

The different terms *"warmth"* and *"heat"* can be used for the communication of global warming: a *heating* of the atmosphere is described as something negative by all students –even the ones who anticipate the *warming* of the atmosphere as something positive. Thus, using the term heat instead of warmth can convince students that global warming – or better, global heating – is a problem. This will not automatically lead to a better understanding of the atmospheric processes or motivate action against climate change. But following the three-step model of action described by Andrey et al. (2000), which begins with the first step "waking an interest" in global warming, provides an important precondition for moving to the second step, "understanding the principles" of global warming, to develop strategies to fight global warming and thus to the third step "motivate for action" against global warming. Recommendations for the communication of climate change ideas will be evaluated in teaching experiments during the second part of our study.

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