IMPROVING STUDENTS' UNDERSTANDING OF GREENHOUSE EFFECT, ACID RAIN AND THE DEPLETION OF STRATOSPHERIC OZONE[1]

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Abstract Global change phenomena, such as an enhancing greenhouse effect, acid rain or the depletion of stratospheric ozone, are considered as environmental problems. Contrary to the demands of Education for Sustainable Development (ESD), three recently published studies have shown that German students still struggle with the acquisition of a scientifically acceptable understanding of these issues. These findings are in accordance with results from international research. Thus, the aim of the research project described in this paper is to enhance students' understanding of the greenhouse effect, acid rain and the depletion of stratospheric ozone. Using the model of Didactical Design Research, teaching and learning materials were developed and empirically tested in Design-Experiments with 14 students in two iterative cycles. The results show that students are able to develop a scientifically acceptable understanding of the atmospheric phenomena by changing their prior conceptions in different ways. For example they can acquire a scientifical understanding of the transformation of radiation in the process of greenhouse effect or they can describe the chemical processes of the formation of acid rain and ozone depletion adequately. Furthermore the results bring out that students struggle with obstacles, e.g. concerning the acquisition of conceptions about radiation or the correct use of technical language.

Keywords: Greenhouse effect, acid rain, ozone depletion, learning processes, Didactical Design Research

1 Introduction

Since the beginning of the 1990s a lot of studies have dealt with the question of students' conceptions about the three phenomena of greenhouse effect, acid rain and the depletion of stratospheric ozone (e.g. Boyes & Stanisstreet, 1992; Cordero, 2000; Fisher, 1998; Khalid, 2003; Maharaj-Sharma, 2009; Pruneau, Gravel, Bourque & Langis, 2003; Stavridou & Marinopoulos, 2001). Due to the fact that the consequences of these three atmospheric phenomena are recognized as challenges for mankind, the United Nations Conference on Environment and Development declared the AGENDA 21 which emphasizes the need for a sustainable development. For the promotion of this idea, education has an important role; the AGENDA 21 claims that "education is critical for promoting sustainable development and improving the capacity of the people to address environment and development issues." (Sitarz, 1993, p. 293)

According to the demands of ESD, a considerable curriculum development has taken place in Germany. The atmospheric phenomena have become part of school curricula of different subjects (e.g. biology, chemistry, physics) and a lot of teaching materials have been developed (e.g. Dittmer et al., 2006; Parchmann & Jansen, 1996; Parchmann, Kaminski & Jansen, 1995; Parchmann, Kaminski, Mester & Paschmann, 1997). However, three recently published studies have shown that German students only have a poor understanding of the scientific background of the three atmospheric phenomena (Harsch, 2013; Niebert, 2010; Schuler, 2011). The results show that students often have little knowledge about the chemical and physical processes in the atmosphere and most students confuse the processes of greenhouse effect and stratospheric ozone depletion.

Because of this we wondered if it is possible for students to acquire a scientifically acceptable understanding of the three phenomena in chemistry lesson. Thus, the project “Atmosphere in Chemistry lesson” deals with the development and the evaluation of teaching and learning materials that intend to improve students’ understanding of the greenhouse effect, acid rain and the depletion of stratospheric ozone. The project is embedded in the interdisciplinary research group FUNKEN at TU Dortmund University which follows the research approach of Didactical Design Research (Prediger et al., 2012; Prediger & Zwetzschler, 2013).

In this paper, we first describe the model of Didactical Design Research. Afterwards we describe the different steps of the research project according to the four working areas of the model of Didactical Design Research.

2 Didactical Design Research – the Dortmund Model

The model of Didactical Design Research combines different ideas of science education research. On the one hand the model aims at developing innovative teaching and learning materials, on the other hand it focuses on the learning process of the students and tries to develop empirical insights into students’ learning pathways and obstacles.

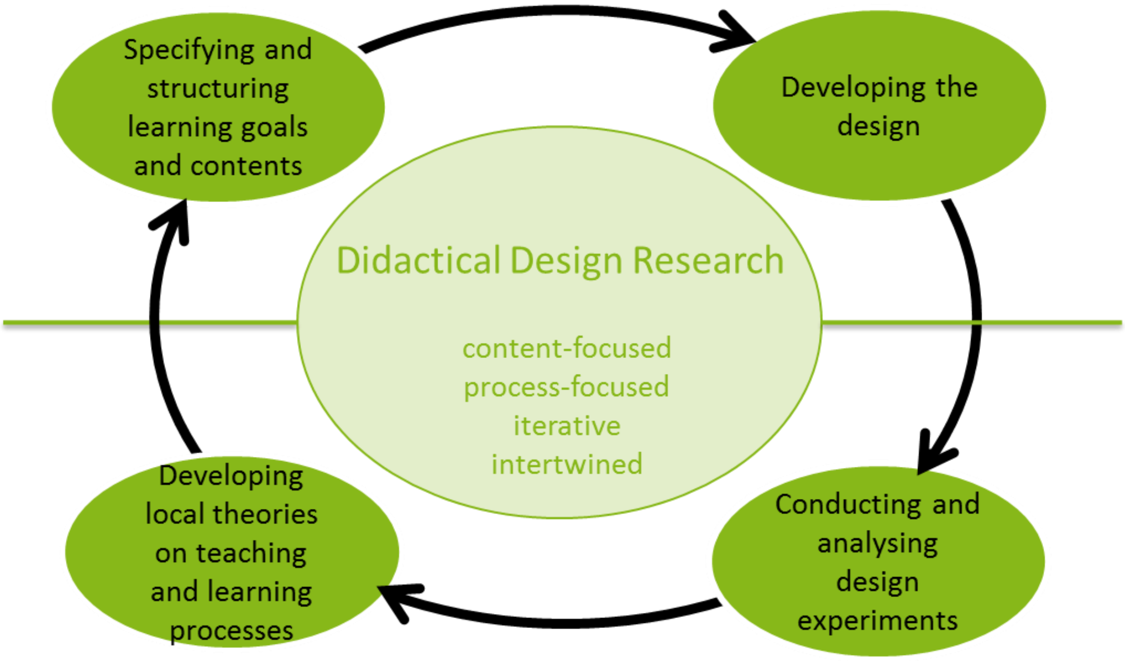

Figure 1. Didactical Design Research in the Dortmund Model. (Prediger & Zwetzschler 2013, p. 411).

In a first step, the learning goals and contents are specified and structured. This working area deals with the questions of *what should be taught* and *why this should be taught*. Consequently, this requires an examination of the content-related specific background. Furthermore the model emphasizes to take into consideration well-known alternative conceptions concerning the learning contents.

The formulated goals are the basis for the development of teaching and learning materials (working area two "Developing the design"). In this working area the question of *how to reach the goals* is being answered by the design of teaching and learning materials. The process of designing is based on empirical and abstract comprehension of teaching and learning as well as on scientific findings about levels of students' performances (e.g. knowledge requirements, common challenges) (Prediger et al., 2012).

In the third working area the teaching and learning materials are tested. For this, design experiments (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003; Komorek & Duit, 2004) are conducted with small groups of students. The analysis of the design experiments aims at understanding the students' learning pathways throughout the design experiment. This means both the identification of the students' conceptual development as well as the identification of obstacles. The results of the analysis are used to develop a local theory of teaching and learning (working area four). Furthermore they are an empirically established basis for a further cycle. Thus, the central idea of this model is "the iterative interplay between designing teaching-learning arrangements, conducting design experiments, and empirically analysing the processes." (Prediger & Zwetzschler, 2013, p. 409)

3 Specifying and structuring learning goals and contents

In the first step, we formulated the goals for teaching. For this, we first regarded the scientific background of the three atmospheric phenomena and afterwards compared this to the state of research about students' understanding of the phenomena

3.1 Scientific background

The greenhouse effect, acid rain and the depletion of stratospheric ozone have in common that they are processes of atmospheric chemistry and physics that occur naturally. There is a natural greenhouse effect, mainly caused by water vapour, acid rain develops from emissions that are discharged due to volcanic eruptions or the formation of lightning and the chemical equilibrium of stratospheric ozone involves nitrogen monoxide (with nitrous oxide as its atmospheric driver). Due to the impact of mankind, the emissions of the responsible pollutants have increased:

- the emission of greenhouse gases (e.g. from burning fossil fuels, deforestation) cause an enhanced greenhouse effect,
- the discharge of sulphur dioxide and nitrogen oxides causes a decrease of pH-level of precipitation and
- the discharge of ozone depleting substances (especially CFCs) has led to a decrease of the stratospheric ozone mixing ratio.

3.2 Consideration of students' understanding

As we already mentioned initially, many students lack an adequate understanding of those processes. There are many studies that identified students' alternative conceptions about their understanding of the greenhouse effect, acid rain and the depletion of stratospheric ozone (e.g. Boyes & Stanisstreet, 1992; Fisher, 1998; Khalid, 2003; Koulaidis & Christidou, 1999; Papadimitriou, 2004; Stavridou & Marinopoulos, 2001). In the past years, the studies of Harsch (2013), Niebert (2010) and Schuler (2011) have documented that German students are often not able to describe the atmospheric phenomena in a scientifically acceptable way as well. In most cases, students fail to distinguish the processes of the greenhouse effect from those of the stratospheric ozone depletion. Instead they think that the greenhouse effect is the result of the ozone hole or vice versa. Sometimes they also confuse these two phenomena with the formation of acid rain. Figure 2 shows a typical idea of students' descriptions of the greenhouse effect.

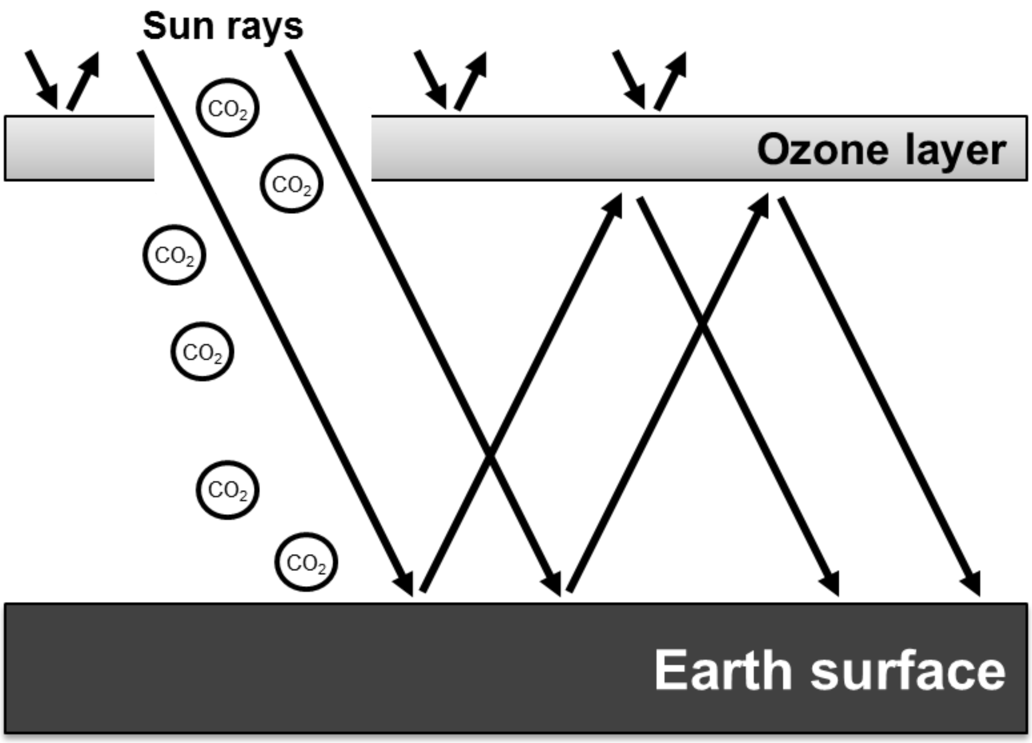

Figure 2. Typical alternative conception of German students about the greenhouse effect. Students think that carbon dioxide causes the ozone hole which enables the penetration of sun rays which are captured between the earth surface and the ozone layer.

In literature, different explanations are discussed why students hold these alternative conceptions. It is said that the use of alternative conceptions

- is fruitful for learners: students can explain how CO_2 contributes to the greenhouse effect;
- is characterized by the use of analogies: students think of the atmosphere as a container. Only if there is a damage on the roof (i.e. the hole in the ozone layer), something (sun rays) can come inside (i.e. between earth surface an ozone layer) and remain there;
- is a result of the facile likeness of the phenomena: the greenhouse effect and the depletion of stratospheric ozone both have to do with some kind of pollution and some kind of radiation. If students do not have a closer look at the involved pollutants or the quality of radiation, they will fail to distinguish the phenomena from each other (acc. to Meadows & Wiesenmayer, 1999; Niebert & Gropengiesser, 2013; Rye, Rubba & Wiesenmayer, 1997; Schuler, 2011).

We think that students should be able to understand the three phenomena in a scientifically acceptable way. Because of this, we think that students should be able both to describe and to differentiate the phenomena from each other by the use of

- the different particles and the different qualities of radiation that are involved in the phenomena,
- the different core processes of the phenomena and
- the respective involved atmospheric layers.

4 Developing the design

The greenhouse effect, acid rain and the depletion of stratospheric ozone are not a part of what we can experience directly. Thus, in many textbooks illustrations are used to describe the processes of the three atmospheric phenomena. Unfortunately, we found that most illustrations in German textbooks are not suitable for students. This is caused by different reasons: most illustrations

- do not show a relation between the different atmospheric phenomena;
- do not focus on central information;
- do not differentiate enough between different radiation or pollutants;
- are mistakable or erroneous concerning central aspects.

We described the aspect of analysing graphical representations and the upcoming problems for students more detailed in Roßbegalle and Ralle (2014a).

4.1 Developing teaching and learning materials

Because of this, we decided to develop own materials for the teaching of the phenomena using multi-level representations (Gilbert & Treagust, 2009; Johnstone, 2006). By reason of the dynamic character of the processes, we decided to teach the phenomena using animated videos. Furthermore we think that it is important to teach the phenomena using three levels of representation. First, the phenomena are taught on a “quasi-atmospheric level” (see figure 3). The students are shown the atmosphere as a composition of different layers which are separated by barriers. All three phenomena are visualized as interactions of different particles or as interactions of particles with radiation in this “atmospheric framework”.

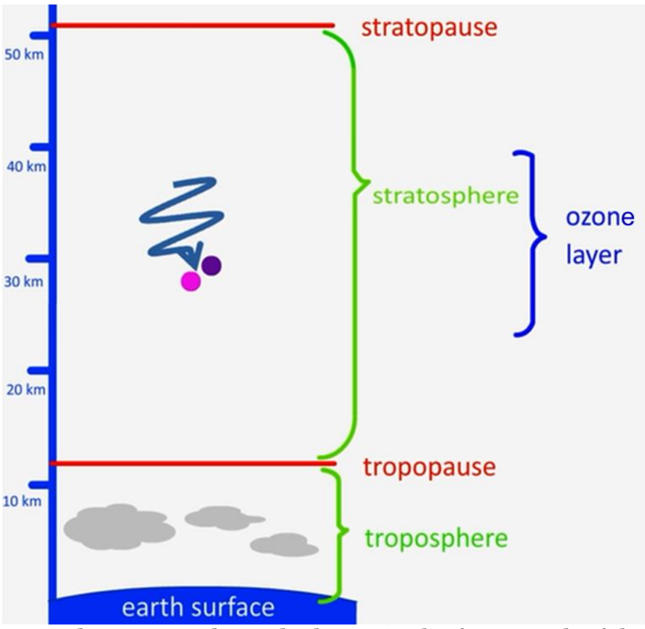

Figure 3. Snapshot from video – ozone layer depletion in the framework of the atmosphere.

Additionally, the core processes are shown on the submicro level. For example, figure 4 shows a screenshot of an animated video in which the depletion of stratospheric ozone by chlorine molecules is illustrated. These illustrations on the submicro level are cross-linked with the chemical equation of the reactions (i.e. $O_3 + Cl \rightarrow O_2 + ClO$ for the reaction shown in figure 4).

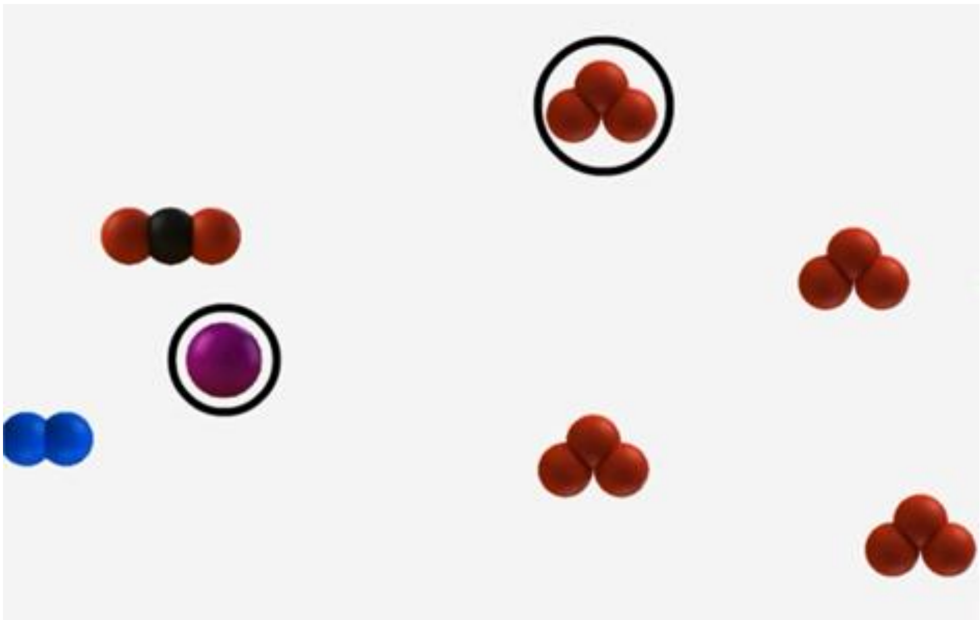

Figure 4. Snapshot from video – depletion of an ozone molecule by a chlorine atom.

4.2 Developing a strategy for conceptual change

We furthermore developed a strategy for the use of these teaching materials in class. For this we both seized suggestions from general strategies to change students' alternative conceptions (Driver, 1989; Scott, Asoko & Driver, 1992) and also strategies that were proposed by studies dealing with the learning of the greenhouse effect (Mason & Santi, 1998; Niebert, 2010; Reinfried, Aeschbacher & Rottermann, 2012), the learning of the greenhouse effect and the depletion of stratospheric ozone (Österlind, 2005) and the learning of acid rain (Marinopoulos & Stavridou, 2002; Stavridou & Marinopoulos, 2001).

In a first step – a phase which we call *Think/Share* – students are asked to reflect on their prior knowledge about the atmospheric phenomena. Afterwards, students work with the instructional material and get to know the scientific description of the phenomena (*Acquire*). Then, students shall compare their prior knowledge and their acquired conceptions in order to reflect on their conceptual development (*Compare*). In the fourth step, students use their new knowledge in a new situation (*Transfer*).

5 Conducting and analysing design experiments

Having developed the teaching and learning materials we went to the third working area which is the empirical evaluation of the developed materials. In so called design experiments groups of two or three students worked with the teaching and learning materials outside the classroom. These design experiments aim at investigating the learning processes that are initiated by the teaching and learning materials. This working area does not intend to show that this design works, instead it is the goal to understand how the design works and which learning processes are in fact initiated (Gravemeijer & Cobb, 2006; Prediger et al., 2012). In these design experiments the interviewer has both the role of a researcher and a teacher. In the role of a researcher he is interested in the students' understanding and their learning processes. In the role of a teacher he helps students to overcome obstacles (Komorek & Duit, 2004).

5.1 Sample

We conducted design experiments with a total of 14 students (8 male, 6 female, aged 14 to 17). In a first cycle of design experiments, we tested the teaching and learning materials with nine students (three groups). On the basis of these first impressions we revised the materials. For example, we found that students developed unwanted alternative conceptions such as the idea that particles decay in the atmosphere (instead of describing a reaction between particles. For further information see Roßbegalle & Ralle, 2014b). Thus, we changed little details in the visualizations and developed supportive tasks. With the reviewed materials we conducted a second cycle of design experiments with five students (two groups). All design experiments were videotaped and conducted by the first author.

5.2 Analysis

For the analysis the videos were transcribed. The analysis focused on

- the reconstruction of students' prior conceptions and their development in the design experiment,
- students' performance in the transfer phase and
- the identification of obstacles.

For this, we conducted a qualitative content analysis in accordance with Mayring (2000). The analysis was conducted with QDA software (MAXQDA11). In the following we present selected results in summary.

5.3 Results

In the analysis of the Think/Share phase we found that the prior conceptions of all groups of students were consistent with well-known-alternative conceptions. For example, students explained

- the greenhouse effect using the idea of a reflection of sun rays,
- the formation of acid rain as a mixing of pollutants with clouds,
- the depletion of ozone as a result of carbon dioxide emissions.

However, we were able to identify that the students' showed dissatisfaction with their prior conceptions when they were discussing their prior knowledge in the group. On the whole we could identify 44 situations in which students showed dissatisfaction with their prior conceptions. It is remarkable that this was found for every group of students. Each group discussed at least their understanding of two phenomena controversially. The dissatisfaction appeared as

- scrutinizing prior conceptions,
- contradicting statements of other students and
- developing diverse descriptions of the phenomena.

When students arrived at the phase of *Acquire*, they were able to change their understanding of the atmospheric phenomena. It is remarkable that the students did not only copy the information that they were presented in the video. Instead they developed hybrid conceptions (acc. to Jung, 1993) that showed a conceptual change in some parts of the understanding but that still contained some alternative conceptions. All groups were able to develop their conceptual understanding further. For example, all groups describes the interaction of radiation and matter in an appropriate way. Furthermore, all groups of students were able to describe the chemical processes adequately instead of using concepts of transport (for the formation of acid rain) or destruction (for the depletion of stratospheric ozone).

The following example illustrates the learning process of Jens', Nils' and Andre's understanding of the interaction between radiation and matter in the process of greenhouse effect.

In the phase of Think/Share the students described the greenhouse effect as follows:

- The major part of *solar radiation* (i.e. UVA rays) reaches the earth surface,
- solar radiation is *reflected* by the earth surface,
- the major part of the *solar radiation* cannot escape to space because of the *ozone layer or particles beyond the ozone layer*,
- the ozone layer *reflects* the *solar radiation* back to the earth surface, and
- this results in a *warming* of the earth.

During the phase of Think/Share the students got into discussion of their description of the greenhouse effect and consequently developed dissatisfaction with it as the following excerpt shows.

Nils:	Well, I think that there are particles beyond the ozone layer and these reflect the solar rays back to the earth again and again.
Jens:	I don't understand what you mean.
Nils:	These particles are beyond the ozone layer.
Jens:	What particles do you mean?
Nils:	Some kind of particles, any kind of pollution. They accumulate beyond the ozone layer and every time solar rays come to it, they get reflected.
Andre:	But does it only reflect in one way or both?
Nils:	What do you mean by both ways?
Andre:	There are some rays coming to the earth from the sun. And if there are particles, they will not only reflect outgoing but also incoming rays.
Interviewer:	So you're wondering how solar rays can come to the earth surface at all?
Andre:	Yes.

Having worked with the animated video, they described the greenhouse in this way:

- The major part of *solar radiation* reaches the earth surface,
- solar radiation gets *absorbed* by the earth surface, it is *transformed* and *infrared radiation* is emitted,
- when infrared radiation reaches the *ozone particles*, it is *absorbed* and then *emitted into random directions* (i.e. back to earth or into space), and
- returned infrared radiation leads to a further *warming* of the earth.

This example shows that these students changed their understanding of the interaction between radiation and matter which is necessary for an adequate understanding of the greenhouse effect. At the same time, the students still say that ozone is a barrier for outgoing radiation (instead of greenhouse gases).

Regarding obstacles in the learning processes, we were able to identify different situations in which students struggled to acquire a scientifically acceptable understanding. In these situations it turned out that the students had problems

- with the use of analogies that they know from everyday life. The students developed alternative conceptions because they do not use analogies in the adequate situations;
- to differentiate adequately between different qualities of radiation. They often mainly struggled with the differentiation of "sun rays";
- with the correct use of technical language. For example, students had problems to decide consciously if it is suitable to say "to mix" or "to react".

6 Developing local theories on teaching and learning processes

6.1 Local theories on learning processes

First, it is remarkable to determine that alternative conceptions of the greenhouse effect, acid rain and the depletion of stratospheric ozone are neither plausible nor fruitful to students. Instead, when discussing these conceptions, students develop dissatisfaction. Thus, students are able to change their understanding of these phenomena when they work with the teaching and learning material. These changes of conceptual understanding are not an adoption of the information that is given but rather a change of the prior conceptions. Accordingly, students' learning processes can be described as a gradual change of prior conceptions towards a scientific understanding. It seems that the advancement of everyday conceptions about pollution, chemical reaction and radiation is a key factor to develop a scientifically acceptable understanding of the atmospheric phenomena.

6.2 Local theory on teaching

With regards to the learning processes we think that teaching the greenhouse effect, acid rain and the depletion of stratospheric ozone should focus on a change of the students' prior conceptions rather than on a replacement. The results imply that the students' understanding should be understood as "missing conceptions" rather than "misconceptions" (acc. to von Aufschnaiter & Rogge, 2010). Thus teaching the atmospheric phenomena should aim at enhancing the students' understanding of conceptions about different pollutants, chemical reactions and radiation. We think that visualizations on the submicro level are a powerful tool to reach this goal.

7. Conclusion

At the end of this paper, we revisit the initial question whether it is possible for students to acquire a scientifically acceptable understanding of the three phenomena in chemistry lesson. After two cycles of Didactical Design Research we come to the point that this is possible. The results underline that students are able to understand the atmospheric phenomena in a scientifically acceptable way when they work with the developed teaching-learning materials. Consequently we think that the teaching-learning materials should be used in regular chemistry lesson for teaching. Due to the fact that there are different obstacles that may occur during the learning process, we think that it is also necessary to continue both the revision of the teaching and learning arrangements as well as the evaluation of the students' learning processes. Hence we think that the model of Participatory Action Research (Eilks & Ralle, 2002) illustrates a suitable approach for the next steps. On the one hand it focusses on the teachers' expertise for implementing the materials in regular chemistry lesson; furthermore it aims at a cyclical process of optimizing the teaching-learning materials in a similar way as the model of Didactical Design Research.

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