“What do adolescents know about atmospheric pollution and how do they think they can help to protect our climate and improve the purity of our atmosphere?” – The answer to these questions is the starting point towards a sustainable future development of the global environment. The purity of the gases that naturally surround our earth is of vital importance for any species living on it. Anthropogenic phenomena such as acid rain, the ozone hole and ozone smog, as well as the increased emission of greenhouse gases and the related climate change have transboundary impacts and are being globally discussed [1]. However, the present global political discussion is rather complex and slow-going. That is why environmental education about these topics should be a requisite in any country: By imparting our expertise about anthropogenic atmospheric phenomena to the young generation, we can lay the foundation for revolutionary rethinking and joint action [2].

In order to put this into practice, two key steps have to be taken: (a) the analysis of the state of knowledge and prevalent misconceptions of adolescents regarding air and atmospheric pollution. Asking adolescents about their understanding of natural science topics, misconceptions are a common problem [3]. And (b) the development of accordant, versatilely applicable curricula for correcting misconceptions and filling knowledge gaps with didactically refined educational material. As the understanding of these topics requires a significant amount of chemical knowledge, chemistry class is the perfect environment for their acquisition [4].

This contribution to the International Conference on Conservation for Better Life (ICCBL 2015) wants to present the results of a correspondent survey carried out in 2012 amongst 1,500 college students from Germany, Spain, apart from two small extra populations in Taiwan and Russia, which will not be discussed in this paper. “All air pollutants are greenhouse gases.” - “The greenhouse effect is caused by the ozone hole.” - “Acid rain provokes chemical burn and cancer.”… Those and other misconceptions, amongst a significant general lack of knowledge, were discovered by this survey [5]. Based on this and the application of the Delphi method to an expert panel of natural science teachers concerning their opinions and experiences, an accordant curriculum for chemistry class was developed and tested on German secondary class students. The learning progress was documented via statistically validated pre-, intermediate- and post-tests [5]. The structure, contents and delectably positive outcomes of the intervention will be presented below. Thus, both the survey and the curriculum make a contribution to the active inclusion of the young generation into the current topic of atmospheric pollution and its effects.

Keywords – Greenhouse effect, ozone, acid rain, misconceptions, empirical study, lecture series

Introduction

Environmental education is an important contribution to greener communities and conservation for a better life. One important area of environmental education is air and atmospheric pollution. The latter comprises some phenomena such as the greenhouse effect, ozone and acid rain. All of these are globally relevant and currently topical: greenhouse gas emissions are rising, the same applies to the trace gases causing acid rain – and the ozone hole is still as large as it was in the 90ies.
Bearing this in mind, the education of the young generation, which will design our global future and has to deal with our environmental heritage, becomes clear. Especially the young people should have a certain knowledge about these global problems and thus have the basics to deal with them and try to solve them.

Based on these thoughts, this paper presents the results of an international empirical survey among 1,500 college students of grade 10 and 12 about air, acid rain, ozone and the greenhouse effect. Based on the findings of the survey, as well as on literature research and expert consultations, a lecture series was developed and applied at school. After a short introduction to the subject fundamentals concerning the four subtopics, the structure and the main results of both the survey and the lecture series will be succinctly presented in this paper.

1. Subject fundamentals

1.1. Air
Our breathing air consists mainly of nitrogen (78 Vol %) and oxygen (21 Vol %). The rest, which is about 1 Vol %, consists of a large share of trace gases such as the greenhouse gases carbon dioxide, methane, nitrous oxide and ozone and many other gases, which, if they exceed their natural atmospheric concentrations, are denominated „air pollutants“ [6].

1.2. Greenhouse effect
In order to understand the functioning of the greenhouse effect, we have to start from the sun: The sun emits visible short-wave radiation to the earth’s surface. The earth absorbs this radiation, transforms it and then re-emits it in form of long-wave heat radiation. The greenhouse gas molecules absorb the heat radiation and then re-emit it into all directions – also back to the earth’s surface [7]. Due to this, our atmosphere retains part of the heat energy and thus maintains a natural global mean temperature of about 15 °C. Without the greenhouse effect, the global mean temperature would be at -18°C.

It is furthermore important to distinguish between the natural greenhouse effect, causing a global mean of 15 °C, and the anthropogenic, that is humanly enforced, greenhouse effect: Due to the humanly caused emissions of greenhouse gases, the current global mean temperature is not at 15,0 but at 16,6 °C [8]. So the greenhouse effect has both a natural and an anthropogenic component.

1.3. Ozone
At about 12 to 19 miles above the earth, the ozone layer is located. The ozone layer is very important to us, as it absorbs all of the skin cancer causing solar UV-C and part of the UV-B radiation.

Apart from that, ozone can also be found in the earth’s troposphere. However, close to the ground, ozone is a negative air component as it irritates our mucous membranes and contributes to the greenhouse effect. Where does the tropospheric ozone come from? – Due to traffic exhaust emissions, nitric oxides (NO\textsubscript{x}) and a group of gases called VOC (volatile organic compounds) are constantly present in our troposphere. High concentrations of VOC and NO\textsubscript{x} in combination with intense sunlight and heat provoke a chemical reaction which leads to the (over-)production of ozone [9].

Meanwhile, in the stratospheric ozone layer, ozone is constantly formed and depleted in a natural chemical reaction cycle (Chapman cycle) involving oxygen and solar radiation. The ozone formation is most effective at the equator, so the main share of the stratospheric ozone is produced above the earth’s equator. Due to global wind systems (Brewer-Dobson circulation), this ozone is then constantly diverted to the Polar

---

As from now, the following abbreviations apply:
GE: Greenhouse Effect
OZ: Ozone (stratospheric and tropospheric)
AR: Acid Rain
Regions. However, during the polar winter term, an annual strong polar vortex arises and blocks the ozone supply, especially in the Antarctic region [10]. During this season, the humanly emitted CFC (chlorofluorocarbon) molecules come into action and deplete the ozone within the vortex. So, each year during the polar spring term, a large ozone hole emerges above the Antarctic continent. As CFC molecules have extremely large lifespans, the ozone hole is still a current problem today in Australia.

1.4. Acid Rain
Some of the gases emitted by traffic and industrial processes, produce acidic solutions whenever they get in contact with (rain) water. These gases are sulphur dioxide (SO$_2$), sulphur trioxide (SO$_3$) and nitrogen dioxide (NO$_2$) as well as carbon dioxide (CO$_2$). They produce solutions of sulphurous acid, sulphuric acid, nitrous acid, nitric acid and carbonic acid. Most of these acids are rather strong and cause the rain water to show pH values below 5.0. However, it is also important to take in mind that even unadulterated rainwater is always slightly acidic: This is because of the carbon dioxide, which is a frequent natural trace gas in our atmosphere and produces a slightly acidic solution with a pH of 5.6.

Acid rain can cause damages to the vegetation, to waters and to monuments [11]. Looking at the vegetation, many forest are harmed by acid rain. Nowadays, this is combined with biological stress caused by tropospheric ozone and the climate change. Concerning waters, the example of the long-lasting acidification of many Norwegian lakes due to emissions from England during the 80ies shows that acid rain is a longsome and transboundary problem. Another negative effect of acid rain is the damage it causes to monuments made of calcium carbonate. If they are exposed to acid rain, the calcium carbonate is converted into calcium sulfate, which is a much softer and can thus be easily eroded.

Nowadays, the emission volumes of nitrogen, sulfur and carbon dioxide are globally rising, especially in the emerging nations such as Asia, India and the Middle East [12]. On the other hand, the European rates are actually decreasing or at least not strongly rising. This is due to the implementation of catalyzers and environmental politics, which clearly show their effect

2. Empirical Study
The following part of this paper presents the results of an empirical study about the state of knowledge of college students regarding the four subtopics.

2.1 Questionnaire and Target Group
The target group of the survey consisted of 1,500 pupils of grade 10 and 12 in secondary schools in Germany and Spain. The pupils received a questionnaire with open and closed questions concerning their attitude and motivation towards environmental protection as well as questions about their personal learning background. The main part of the questionnaire however tested their technical knowledge about the four topics of interest.

2.2 Principal Findings of the Empirical Study
Almost regardless of age and country, the evaluation of the survey revealed a significant lack of knowledge, as well as several misconceptions throughout all four subject areas. The most important findings will be presented in the following. In order to give a total overview, the percentages always refer to the entire student population (that is, grade 10 and 12 together). More detailed results, incorporating age and country differences, can be found in [13].

Asking the students about the main air components, 78 % nitrogen and 21 % oxygen, only a mere 20 % of the students were able to give the correct reply, while most of the others over-estimated the carbon dioxide rate and/or sub-estimated the
nitrogen rate. Looking at the minor air components and letting the students describe their notions of trace gases, air pollutants and greenhouse gases, it becomes clear that most of them don’t differentiate between these three terms. Hence, to many of the students „all trace gases are air pollutants“ and „all air pollutants are greenhouse gases“.

Concerning the greenhouse effect, a 30 % of the surveyed pupils were able to give a correct description of how the GE works. When asked about the most significant greenhouse gases, only a mere 28 % of the pupils mentioned water vapour. Thus, it can be deduced that most of the students regard the GE to be completely anthropogenic (caused by humanity). Another very important misconception which can be found in the majority of the students consists in stating an interdependency between the GE and the ozone hole. To many of the students „the greenhouse effect causes the ozone hole“ or „the ozone hole causes the greenhouse effect“.

The topic „ozone“ (which incorporates both stratospheric and tropospheric ozone) showed low values for the recognition of tropospheric (ground level) OZ, which was known by only 21 % of the students. Stratospheric OZ, however, received better results, with a 44 % of the pupils naming the correct geographic location of the ozone hole (Antarctica) and again 44 % mentioning CFCs as a major factor for the depletion of stratospheric OZ. On the whole, it may be stated that for many students „ozone exists only in the ozone layer“.

Furthermore, for those who did not know about the ozone hole above Antarctica, „the ozone hole is located above the industrial countries“, that is, above the countries with the highest emission rates.

The last part of the survey treated with acid rain. Here, the findings were that a 55 % of the pupils knew sulphur dioxide and nitrogen dioxide to cause AR, a 44 % furthermore correctly mentioned carbon dioxide and a 35 % were able to name some consequences of AR (e.g. deterioration of monuments, damage to forests and acidification of lakes). Regarding misconceptions, it can be deduced that those pupils who did not mention carbon dioxide, might be of the opinion that “acid rain is completely anthropogenic”. Apart from that, some of the students believe that “acid rain is concentrated acid”.

3. Lecture Series

The last part of this research project comprises the conception and application of a lecture series about air and atmospheric pollution. Regarding the conception, the results of the above described empirical study, as well as extensive literature research and expert interviews were accounted for.

3.1 Conceptual Design

The conception of the lecture series comprised three working stages.

The first stage consisted in analysing the knowledge level and the possible misconceptions of the target group concerning air, GE, OZ and AR. This was done via the empirical study described in chapter 2 of this paper. These results were furthermore compared to already published findings in literature. As a second step, extensive literature research was done concerning already existent teaching concepts about these topics. Out of this, possible didactical approaches were developed and then discussed with experts (such as teachers and scientists).

Based on these findings, a lecture series was developed. The lecture series is composed of 7 school lessons which are surrounded by a pre- and a post-test and can be divided into three parts: First, the students take three lessons to acquire basic knowledge about the 4 subtopics air, GE, OZ and AR by means of expert learning. Then, the teacher uses one
lesson to introduce a concept map in order to both recapitulate the basics and point out thematic interrelations. And finally, there are three lessons of teacher-class dialogue and experiments incorporating further knowledge about GE, OZ and AR.

3.2 Main Results of the Lecture Series
The main learning results of the lecture series can be seen in Figure 1 and Figure 2. Figure 1 shows the knowledge level of the pre-test in comparison with the post-test results. The improvement rates were 12 % for air, 20 % for GE, 29 % for OZ and 34 % for AR. On the hole, the pre-knowledge level was 43 % and the post-knowledge level was 67 %, which makes a general performance improvement of 24 %.

Figure 1: Lecture series – results of the pre-test vs. post-test

Figure 2 shows the knowledge level of an independent test (= pupils not taking part in the lecture series) of grade 12 in comparison with the post-test results (grade 10). Despite their younger age, the grade 10 students performed better than the ones of grade 12. The rate differences were 1 % for air, 25 % for GE, 25 % for OZ and 29 % for AR. On the hole, the knowledge level of the grade 12 students was 47 % and the (post-)knowledge level of the grade 10 students was 67 %, which makes a 20 % higher general performance of the latter.

4. Conclusions
The topic „air and atmospheric pollution“ is demanding and due to the complexity of the subject area, there is still room for further improvement of the lecture series. A survey amongst German college teachers showed their interest in the incorporation of the lecture series in their class, which is an important premise for its implementation. In order to assure the quality of the tuition, teachers’ trainings are very important.

Bibliography
und daraus hervorgehende Konsequenzen für den naturwissenschaftlichen Unterricht.
(Air, greenhouse effect, ozone and acid rain: Knowledge state and misconceptions of senior class students and accordant consequences for natural science class.) Dissertation, 390 pages. Muenster: Schueling.


